PB82-102526

Assessment and Control of Chrysotile Asbestos Emissions from Unpaved Roads

Midwest Research Inst.
Raleigh, NC

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

May 81

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-81-006
May 1981

Air

PB82-102526

Assessment and Control of Chrysotile Asbestos Emissions from Unpaved Roads

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/3-81-006	2.	3. RECIPIENT'S ACCESSION NO. PB82 102526
4. TITLE AND SUBTITLE Assessment and Control of Chrysotile Asbestos Emissions from Unpaved Roads		5. REPORT DATE May 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Robert K. Serra Michael A. Connor, Jr.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS MIDWEST RESEARCH INSTITUTE 4505 Creedmoor Road, Suite 202 Raleigh, N.C. 27612		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3059 ESED Project No. 77/6
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Studies Branch Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES

U.S. EPA Project Officer--William Larry Elmore, Emission Standards and Engineering Div.

16. ABSTRACT

This document summarizes the findings of field surveys and a test program to assess chrysotile asbestos emissions generated by vehicular use of unpaved roads surfaced with crushed serpentinite rock. Included in this document are discussions of Federal asbestos regulations, sampling and analysis procedures, human health effects, and various emission control techniques. EPA believes that asbestos emissions which occur from unpaved roads and other dusty sources surfaced with serpentinite should be reduced to the greatest extent practical. Local, State, and Federal agencies responsible for road maintenance in the limited areas where asbestos emissions occur are in the best position to assess local conditions and implement the most appropriate control measures.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Chrysotile asbestos Air pollution Fugitive dust Asbestos Hazardous pollutants Unpaved roads Control methods	Air pollution control	13 B

18. DISTRIBUTION STATEMENT Unlimited. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 105
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-450/3-81-006

Assessment and Control of Chrysotile Asbestos Emissions from Unpaved Roads

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

May 1981

EPA REVIEW NOTICE

This report has been reviewed by the U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policy of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TABLE OF CONTENTS

Section	Title	Page
List of Tables		iv
List of Figures		vi
CHAPTER 1	SUMMARY	1-1
CHAPTER 2	ASBESTOS MINERALOGY, REGULATIONS, MEASUREMENT, TECHNIQUES, ENVIRONMENTAL CONTAMINATION, FIBER AERODYNAMICS, AND HUMAN HEALTH EFFECTS	2-1
2.1	Asbestos Mineralogy	2-1
2.2	OSHA, MSHA, and EPA Asbestos Regulations	2-2
2.3	Asbestos Measurement Techniques	2-5
2.4	Environmental Contamination	2-6
2.5	Asbestos Fiber Aerodynamics	2-7
2.6	Human Health Effects Associated With Inhalation of Asbestos	2-9
2.7	References for Chapter 2	2-16
CHAPTER 3	EXPOSURE ASSESSMENT FOR CRUSHED STONE CONTAINING CHRYSOTILE	3-1
3.1	Detection of Asbestos Emissions in Maryland in 1976	3-1
3.2	Nationwide Investigation of Chrysotile Emissions From Roadways and Quarries	3-2
3.3	Asbestos Sampling, 1979	3-7
3.4	EPA Response to Advance Notice of Proposed Rulemaking (42 FR 58543)	3-10
3.5	References for Chapter 3	3-12
CHAPTER 4	EMISSION CONTROL ALTERNATIVES AND ADMINISTRATIVE OPTIONS	4-1
4.1	Introduction	4-1
4.2	Emission Control Alternatives	4-1

TABLE OF CONTENTS

Section	Title	Page
4.3	Administrative Options	4-15
4.4	References for Chapter 4	4-17
CHAPTER 5	CONCLUSIONS AND RECOMMENDATIONS	5-1
5.1	Conclusions	5-1
5.2	Recommendations	5-1
APPENDIX A	FEDERAL ASBESTOS REGULATIONS	A-1
APPENDIX B	SAMPLING AND ANALYSIS OF AIRBORNE CHRYSOTILE ASBESTOS CONCENTRATIONS AT FIVE TEST SITES	B-1
B.1	Test Program Description	B-1
B.2	Sample Filter Handling	B-3
B.3	Sample Analysis	B-5
B.4	Site-Specific Tests: Description and Results	B-7
B.5	Laboratory Comparisons	B-19
B.6	Quality Assurance	B-19
B.7	Conclusions	B-19

LIST OF TABLES

Table	Title	Page
Table 2-1	Physical, Chemical, and Mineralogical Properties of Varieties of Asbestos	2-3
Table 3-1	States Where Deposits of Serpentinite Rock Occur	3-4
Table 3-2	Quarries Producing Crushed Serpentinite Containing Chrysotile Confirmed Through Petrographic and/or EM Analysis of Stone Product	3-5
Table 3-3	Unpaved Roads Surfaced With Quarried Serpentinite and the Estimated Number of Nearby Residents	3-6
Table 3-4	Serpentinite Quarries and Unpaved Roads Located on Federal Lands	3-8
Table 4-1	A Comparison of Control Alternatives for Reducing Chrysotile Emissions From Unpaved Roads	4-2
Table 4-2	Dust Suppressant Manufacturers	4-7
Table 4-3	Performance Ratings and Road Conditions for Selected Road Stabilizers Mixed into Soil	4-13
Table 4-4	Performance Ratings and Road Conditions for Selected Road Dust Suppressants, Spray-On Application	4-14
Table A-1	Occupational Safety and Health Administration Asbestos Regulations	A-2
Table A-2	Mine Safety and Health Administration Asbestos Regulations	A-4
Table A-3	Environmental Protection Agency Asbestos Regulations	A-5
Table A-4	Consumer Product Safety Commission Asbestos Regulations	A-8
Table A-5	Food and Drug Administration Asbestos Regulations	A-9
Table B-1	Analysis of Eight Crushed Stone Samples for Chrysotile Fiber and Mass Content Performed by the University of Minnesota at Duluth	B-21
Tables B-2 through B-8	Sampling and Analysis of Chrysotile Asbestos Emissions From Holy Cross Road	B-22 through B-28

LIST OF TABLES
(concluded)

Table	Title	Page
Tables B-9 through B-15	Sampling and Analysis of Chrysotile Asbestos Emissions From McNabb Road	B-29 through B-35
Table B-16	Sampling and Analysis of Ambient Chrysotile Asbestos Concentrations in the Clear Creek Federal Recreational Area, San Benito County, California	B-36
Table B-17	Sampling and Analysis of Chrysotile Asbestos Emissions Near a Serpentinite Quarry in the Eastern United States	B-37
Table B-18	Sampling and Analysis of Chrysotile Asbestos Emissions Near a Serpentinite Quarry in the Western United States	B-38
Table B-19	Statistical Evaluation of Chrysotile Fiber Concentrations Reported by Two Laboratories Analyzing Split and Colocated Samples	B-39

LIST OF FIGURES

Figure	Title	Page
Figure 2-1	Distribution of Ultramafic and Metamorphic Rock Formations in the United States	2-4
Figure 2-2	Comparison of Asbestos Fibers and Other Particles By Size and Measurement Techniques	2-8
Figure B-1	Site 1--Holy Cross Road, Harford County, Maryland . .	B-8
Figure B-2	Chrysotile Fiber Concentrations (Geometric Average) Versus Downwind Receptor Distance for Seven Sampling Runs at Holy Cross Road	B-10
Figure B-3	Total Suspended Particulate Concentrations for Two Days of Sampling at Holy Cross Road	B-12
Figure B-4	Average (Geometric) Chrysotile Fiber Concentrations Versus TSP Concentrations for Two Sets of Runs with 2 Different Chrysotile (By Weight) Concentrations in the Roadstone	B-13
Figure B-5	Site 2: McNabb Road, Harford County, Maryland	B-14
Figure B-6	Upwind and Downwind Chrysotile Fiber Concentrations (Geometric Average) for Seven Sampling Runs at McNabb Road	B-16

1. SUMMARY

Asbestos is a commercial term for the following group of naturally occurring fibrous minerals: chrysotile, crocidolite, cummingtonite-grunerite asbestos, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos. The most widely used form of asbestos is chrysotile, which is found in serpentinite rock deposits. Asbestos fibers are released to the atmosphere primarily through human activity and to a lesser degree by natural forces in areas where outcroppings of asbestos-containing rock occur.

Inhalation of asbestos fibers has been associated in humans with asbestosis (diffuse interstitial fibrosis of the lung), respiratory cancer, and mesothelioma (a rare cancer of the pleural and abdominal lining). Researchers have been unable to determine quantitatively if there is a safe level of exposure below which asbestos-induced cancer will not occur. Several studies have shown qualitatively that the risk of asbestos-induced disease increases as the duration and/or intensity of asbestos exposure increases. Currently, there is a lack of agreement in the medical community concerning the relative fibrogenicity and carcinogenicity of short (less than 5 micrometers [μm] in length) versus long (greater than 5 μm in length) fibers. Consequently, the Environmental Protection Agency (EPA) believes that human exposure to all airborne asbestos fibers should be reduced to the greatest extent practical.

In 1977 airborne asbestos mass concentrations about 1,000 times greater than those typically found in urban air were found near unpaved roads surfaced with crushed serpentinite rock in Montgomery County, Maryland. EPA tests indicated that the crushed stone (supplied by a local quarry) contained from 0.1 to 0.7 percent chrysotile by weight. Analysis of airborne particulate samples collected downwind of unpaved roads surfaced with crushed serpentinite showed that vehicular traffic over these roads caused increased asbestos concentrations in the atmosphere. EPA recommended that the State of Maryland and Montgomery County act to control such emissions. Montgomery County responded by paving all unpaved roads surfaced with serpentinite (92 miles of roads) and by removing or covering all such stone in playgrounds or parks.

The Montgomery County Department of Environmental Protection (DEP) conducted additional monitoring studies in 1977-1978 to further assess the uses of crushed serpentinite with respect to asbestos emissions. From these studies, DEP concluded that:

> . . . elevated asbestos levels occurred only on untreated, unpaved road surfaces or on bare stone surfaces with moderate-to-heavy vehicular traffic creating dusty conditions . . . . Using crushed serpentinite on driveways, road shoulders, parking lots, biking paths and other areas of relatively low traffic does not seem to cause elevated ambient asbestos levels . . . . Lightly traveled surfaces should be surfaced with a dust suppressant.

The DEP did not define the terms "elevated asbestos levels" or "moderate-to-heavy vehicular traffic."

Because of the probability that additional unpaved roads in other areas of the country were surfaced with crushed serpentinite, EPA announced that regulations would be proposed to limit the production and use of crushed serpentinite if the Agency determined that the use of such stone was causing asbestos emissions proximate to the public in a number of locations (Federal Register, November 10, 1977). In order to determine the need for a regulation, EPA undertook a study with the following objectives: (1) to determine the extent to which quarrying operations are being conducted in the United States in serpentinite rock deposits, (2) to measure the chrysotile concentration of the rock being quarried, (3) to locate areas where crushed serpentinite is used to maintain unpaved public roads, (4) to determine if the use of crushed serpentinite for road surfacing results in elevated airborne chrysotile concentrations, (5) to estimate the number of individuals potentially exposed to asbestos emissions from these roads, and (6) to recommend control alternatives.

A nationwide study of the quarry industry found only 12 private quarries that produce crushed serpentinite. The chrysotile content of the stone from these quarries ranges from trace amounts to 2.7 percent by weight. Crushed serpentinite from five of these quarries is used to maintain about 400 miles of county roadways in California, Virginia, North Carolina, and Maryland. An estimated 6,500 people reside within approximately 200 feet of these roads. Serpentinite from the remaining seven quarries is not used for surfacing unpaved public roads.

The U.S. Forest Service (USFS) has determined that approximately 30 quarries on Federal lands in California and Oregon produce crushed serpentinite stone. Crushed stone from these quarries is primarily used to maintain about 300 miles of intermittently used logging roads on Federal forest lands. In the same general vicinities, approximately 1,000 miles of unpaved roads have been constructed over natural outcroppings of serpentinite. A massive outcropping of serpentinite also occurs in San Benito County, California, where a 43,000-acre Federal recreation area is maintained by the Bureau of Land Management (BLM). The USFS and BLM are further assessing the occurrence and use of serpentinite on Federal land.

EPA conducted an extensive air sampling program in 1979 to assess chrysotile fiber concentrations near several unpaved roads with serpentinite surfaces and near two serpentinite quarries. Sampling was conducted at the road sites to determine if there is a quantitative relationship between the level of asbestos emissions and three major variables: chrysotile content of the crushed stone, traffic characteristics, and local meteorological conditions. A total of 153 airborne particulate samples and 10 crushed rock samples from the various sampling sites were analyzed for chrysotile by transmission electron microscopy (TEM). These analyses indicate that chrysotile concentrations downwind of unpaved roads surfaced with crushed serpentinite (containing less than one percent chrysotile) are significantly higher statistically than upwind concentrations when light to moderate traffic occurs across the roadways. Specifically, chrysotile fiber concentrations as high as 1.33 fibers/ml were measured 61 meters downwind of an unpaved road when 20 vehicle passes occurred during a 2-hour sampling period. The crushed road stone was found to contain 0.14 percent chrysotile (by weight). Higher chrysotile fiber concentrations were found closer to the roadways. Because of variations in the sampling data, no statistical relationship was determined concerning the influence of downwind distance, chrysotile content of the road stone, traffic conditions, or wind speed on chrysotile emissions. Analysis of airborne particulate samples collected near two serpentinite quarries indicates that serpentinite quarries are not a major source of airborne asbestos to the surrounding area.

Small concentrations of amphibole fibers were found in some airborne particulate and crushed stone samples. These concentrations are not reported with the test results in Appendix B because the purpose of this study was to assess chrysotile emissions from crushed serpentinite and because not all the participating laboratories had the analytical capability to positively identify amphibole fibers. It should also be noted that chrysotile fiber concentrations reported in this document are not directly comparable to asbestos concentrations found in occupational settings. This study's chrysotile results were determined by electron microscopy. Analysis of samples collected in the workplace is conducted using phase contrast microscopy, which is not mineral-specific. In addition, nearly all the chrysotile fibers detected in this study were shorter than 5 µm in length and less than 1 µm in diameter and thus would not have been detected by techniques other than electron microscopy.

EPA believes that asbestos emissions from unpaved roads and other dusty sources (such as unpaved parking lots) should be reduced to the greatest extent practical. Survey information and field studies found that asbestos emissions from unpaved roads surfaced with crushed serpentinite are limited to a few locations in the United States and may affect a very small segment of the general population. The level of asbestos emissions as well as the most appropriate method to control those emissions varies with location. EPA has concluded that local, State, and Federal agencies that maintain these roads are in the best position to assess local conditions and implement the most appropriate control measures.

EPA has developed this document to inform officials about asbestos emissions within their jurisdictions and to provide those officials with information concerning various methods to control asbestos emissions from unpaved roads. Effective emission control techniques include paving, applying chemical dust suppressants, removing and/or replenishing crushed roadstone, and controlling traffic. In addition, administrative and regulatory options are available to State and local officials to ensure that crushed serpentinite is not used for maintaining unpaved public roads.

2. ASBESTOS MINERALOGY, REGULATIONS, MEASUREMENT, ENVIRONMENTAL CONTAMINATION, FIBER AERODYNAMICS, AND HUMAN HEALTH EFFECTS

2.1 ASBESTOS MINERALOGY

Asbestos is a commercial term for the following group of naturally occurring fibrous minerals: chrysotile, crocidolite, cummingtonite-grunerite asbestos, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos. The term "asbestos fiber" is used to define a particle of any of the above-mentioned minerals having an overall length-to-width ratio of 3:1 or greater and with substantially parallel sides. EPA does not recognize the distinction made by other Federal agencies that such a particle must also be at least 5 µm in length to be considered an asbestos fiber.

Asbestos varieties belong to either the serpentine group or the amphibole group of minerals. Chrysotile is the fibrous variety of the serpentine group. Rock containing mainly serpentine minerals (serpentinite) usually contains chrysotile asbestos. Chrysotile fibers are spirally wound, hollow tubes with a curved morphology. The chemical bonding between individual tubes is very weak, and fibers can separate into fibrils (smaller fibers) as thin as the diameter of an individual tube. Individual fibrils measure from 0.02 to 0.035 µm in diameter. Chrysotile accounts for more than 90 percent of all asbestos used commercially.

The fibrous amphibole varieties--cummingtonite-grunerite asbestos, anthophyllite asbestos, crocidolite, tremolite asbestos, and actinolite asbestos--have straight and solid fibers generally larger in diameter than chrysotile fibers. The fibrous amphiboles are found in metamorphic rock and account for the remaining 10 percent of asbestos used commercially.

The unique physical, chemical, and mineralogical properties of asbestos varieties that make the use of these fibers attractive to industry are shown in Table 2-1. The geologic areas of the United States where asbestos generally is most likely to occur are shown in Figure 2-1.

2.2 OSHA, MSHA, AND EPA ASBESTOS REGULATIONS

The first standard in the United States that limited worker inhalation of asbestos fibers was promulgated by the Occupational Safety and Health Administration (OSHA) in 1971. The regulation was revised in 1972 and in 1976 (see Appendix A, Table A-1). The current standard limits worker exposure (an 8-hour, time-weighted average) to a maximum of two fibers, longer than 5 µm in length, per cubic centimeter of air. Exposure may not exceed 10 fibers per cubic centimeter at any time, as determined by the membrane filter technique at 400 to 450 magnification with phase contrast illumination. The Mine Safety and Health Administration (MSHA) has a similar standard except that the 10-fiber-per-cubic-centimeter ceiling value may be exceeded for a total of 1 hour each 8-hour day (see Appendix A, Table A-2).

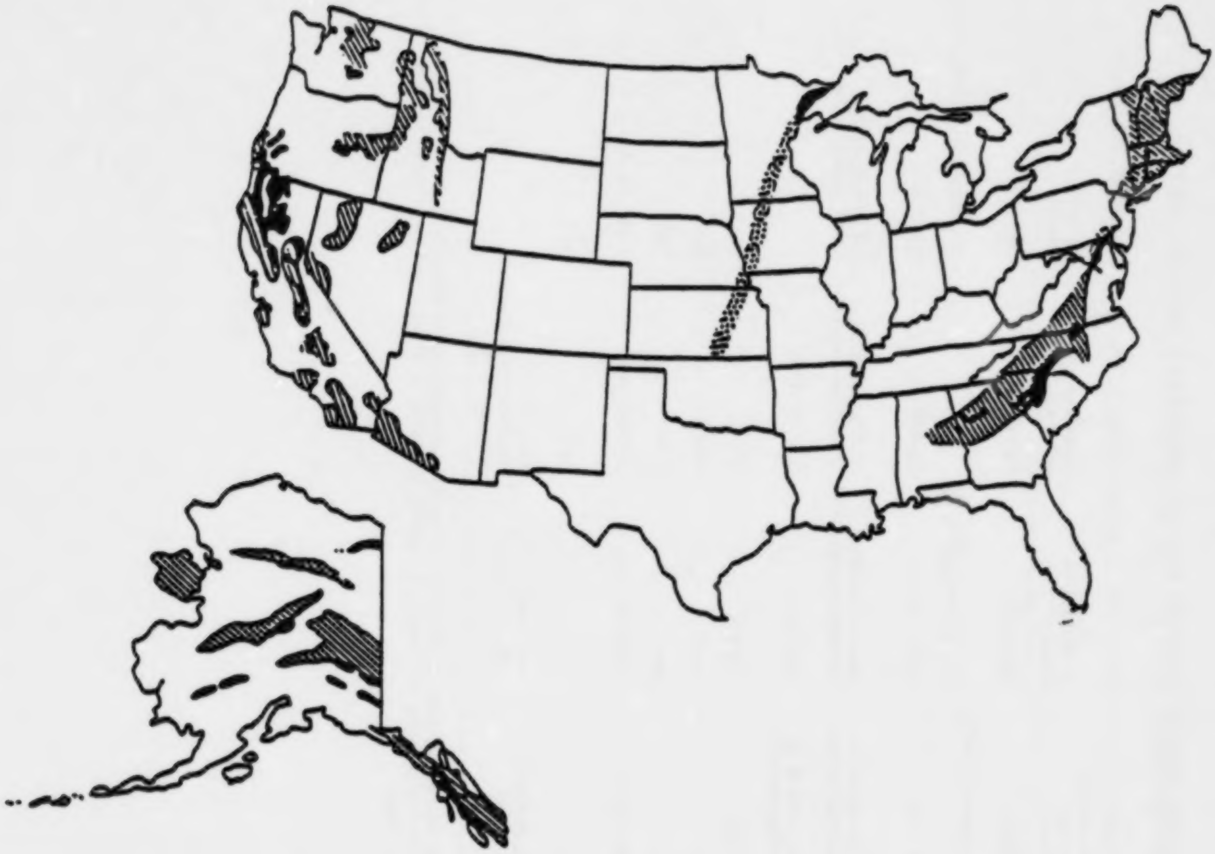
The National Institute of Occupational Safety and Health (NIOSH) acknowledges that OSHA's standard is designed to prevent asbestosis and states that there is insufficient information to establish a standard to prevent asbestos-related neoplasms other than a standard that limits worker exposure to zero asbestos emissions.[4] In April 1980 NIOSH recommended lowering the exposure standard to 0.1 fiber/ml from the current standard of 2 fibers/ml because the lower value represents the lowest level that can be measured accurately by currently available optical microscope techniques.[4]

EPA listed asbestos as a hazardous air pollutant in 1971. The Agency has followed a policy of limiting asbestos emissions to the greatest extent practical through the use of procedural and visible emissions standards. Subsequently, EPA has prohibited surfacing roads with asbestos mine tailings, prohibited visible asbestos emissions from asbestos mills and manufacturing facilities, established work practice standards for the demolition of buildings containing asbestos, limited the asbestos content of materials used to insulate or fireproof buildings and pipes, and given guidance for assessing and removing asbestos-containing materials from school buildings. (See Appendix A, Table A-3).

TABLE 2-1. PHYSICAL, CHEMICAL, AND MINERALOGICAL PROPERTIES OF VARIETIES OF ASBESTOS[1] [2]

Property	Chrysotile	Crocidolite	Cummingtonite-Grunerite asbestos	Anthophyllite asbestos	Tremolite asbestos	Actinolite asbestos
Mineral group	Serpentine	Amphibole	Amphibole	Amphibole	Amphibole	Amphibole
Chemical formula	$Mg_3Si_2O_5(OH)_4$	$Na_2Fe_5Si_8O_{22}(OH)_2$	$(Fe,Mg)_7Si_8O_{22}(OH)_2$	$(FeMg)_7Si_8O_{22}(OH)_2$	$Ca_2(MgFe)_5$	$(Ca_2(MgFe)_5Si_8O_{22}(OH)_2$
Crystal system	Monoclinic and orthorhombic	Monoclinic	Monoclinic	Orthorhombic	Monoclinic	Monoclinic
Optical properties	Biaxial positive, extinction parallel	Biaxial ±, extinction parallel	Biaxial positive, extinction parallel	Biaxial positive, extinction parallel	Biaxial negative, extinction parallel	Biaxial negative, extinction parallel
Resistance to destruction by heat	Good, brittle at high temperatures	Poor, fuses	Good, brittle at high temperatures	Very good	Fair to good	--
Hardness[a]	2.5-4.0	4	5.5-6.0	5.5-6.0	5.5	6±
Flexibility	High	Good	Good	Poor	Poor	High
Spinnability	Very good	Fair	Fair	Poor	Poor	Poor
Tensile strength, lb/in.^{2}	824,000 max.	876,000 max.	16,000-90,000	4,000 and less	1,000-8,000	1,000 and less
Resistance to acids	Poor	Good	--	--	Good	Good
Color	Green, gray, amber to white	Blue	Gray, yellow to dark brown	Yellowish brown, grayish white	Gray-white, greenish-yellowish, bluish	Greenish

[a] Working scale of hardness: 1--very easily scratched by fingernail and has greasy feel to the hand; 2--easily scratched by fingernail; 3--scratched by brass pin or copper coin; 4--easily scratched by knife; 5--scratched with difficulty with knife; 6--easily scratched by file; 7--little touched by file but will scratch window glass. All harder than 7 will scratch window glass.



■ Ultramafic rocks, mafic plutonic rocks, and similar basic intrusives. Ultramafic rock is very low in silica and rich in iron and magnesium minerals. Serpentinite is a type of ultramafic rock.

▨ Areas of extensive high-rank (severe) metamorphism where amphiboles are most likely to be found.

▩ Inferred ultrabasic intrusive rock where amphiboles may be found.

NOTE: In Hawaii, the type of mineral alteration that could lead to formation is quite restricted (to the vicinity of the Koolau and Molokai volcanoes on the island of Oahu).

Figure 2-1. Distribution of ultramafic and metamorphic rock formations in the United States.[3]

2.3 ASBESTOS MEASUREMENT TECHNIQUES

2.3.1 Air Sample Analyses

Airborne particles are initially collected on the surface of a small-pore size filter through which a known volume of air is drawn. Asbestos fiber concentrations are then estimated by either phase contrast microscopy (a special application of the optical microscope) or by electron microscopy (EM). In general, asbestos fiber concentration data obtained by one of these two methods cannot be converted to a concentration determined by the other method. In phase contrast microscopy, a section of a membrane filter is viewed at 400 magnification, and all particles which have at least a 3:1 length-to-width ratio and a length of 5 μm or greater are counted as asbestos fibers. Fibers smaller than 0.1 μm in diameter are not visible by phase contrast microscopy. Consequently, identification of smaller size fibers which may be of biological significance is precluded. Fiber counting by phase contrast microscopy is based entirely on particle shape and is not specific for asbestos. This method is the standard method for measuring asbestos in the workplace. In cases where all fibers are smaller than 5 μm in length or thinner than 0.1 μm in diameter, no detectable fiber count will result.

By comparison, electron microscopy permits positive identification of asbestos fibers that are not observable by phase contrast microscopy. Chrysotile fibers are relatively easy to distinguish from other types of fibers because of their unique tubular structure. Selected area electron diffraction (SAED) and energy dispersive X-ray diffraction (EDX) are often used to substantiate fiber identification. In EM analysis, only a very small fraction of the filter is viewed at a magnification of 15,000 to 20,000 X.

When determining asbestos concentrations in airborne particulate samples by either phase contrast microscopy or EM, visible fiber counts are used to estimate the total fiber count for the whole filter. The accuracy of the calculated fiber concentration is primarily dependent upon the representativeness of the fiber population actually counted.

The method of sample preparation and fiber counting strongly influence the results obtained by EM. EPA developed a provisional methodology in

1977 that optimized various techniques for analyzing and counting airborne asbestos fibers by EM. Testing of the provisional methodology showed interlaboratory variation in fiber concentration results to be about20 percent for samples collected in an industrial setting and samples prepared in the laboratory.[5] [6]

2.3.2 Bulk (Rock) Sample Analysis

Petrographic microscopy is the principal method for examining bulk samples (such as a rock sample). This technique is relatively straightforward and reliable for qualitative identification and characterization of crystalline substances, including asbestos.

Quantitative analysis of asbestos in a bulk sample is determined by EM. A small representative portion of rock powder is ground from a bulk sample and is uniformly dispersed onto a filter media. A small fraction of the filter is then viewed at high magnification, and asbestos mass and fiber concentrations are estimated. Careful consideration must be given to sample preparation, especially during the grinding phase. Chrysotile is usually present in microveins that tend to disintegrate into small chunks. These chunks must be given sufficient grinding time to divide into free fibers. A methodology for analysis of asbestos in rock samples was published by EPA in December 1978.[7] The methodology is summarized in Appendix B.

2.4 ENVIRONMENTAL CONTAMINATION

Asbestos fibers and fiber bundles are released to the atmosphere primarily by human activity (such as mining, processing, manufacturing, and the use of asbestos-containing products). Natural phenomena (weathering and erosion of outcroppings of asbestos-containing rocks) normally contribute in a small way to asbestos fiber emissions in the local environment. Very little is known about ambient airborne asbestos fiber concentrations in the United States and even less is known about how these concentrations vary geographically and by season. The few environmental studies conducted prior to 1976 determined airborne asbestos mass concentrations only, thus are of minimal value in assessing recent airborne fiber concentration data.

EPA conducted a study to determine ambient asbestos mass concentrations in 55 cities in the United States. Biweekly air samples were collected and composited for analysis in 3-month periods during 1969 through 1973. Of the 518 quarterly ambient asbestos mass concentrations measured by EM, 97 percent were less than 100 ng/m^3,* 90 percent less than 50 ng/m^3 and 38 percent less than 10 ng/m^3.[8]

Mt. Sinai School of Medicine conducted a study for EPA in 1972 to determine asbestos air concentrations inside and outside of 19 buildings (in urban settings) fireproofed with asbestos-containing spray materials. For most of the samples analyzed, there was no significant difference between asbestos concentrations measured within the buildings and those measured outside at the same site. The average asbestos mass concentration (determined by EM) at a given outdoor site varied from 0 to 87 ng/m^3.[9]

The State of Connecticut Department of Environmental Protection conducted monitoring studies in 1975 and 1976 to determine ambient concentrations throughout the State. Asbestos mass concentrations at rural and urban sites generally ranged below 10 ng/m^3. At sites located near industrial sources of asbestos, airborne concentrations averaged about 30 ng/m^3.[10]

2.5 ASBESTOS FIBER AERODYNAMICS

As shown in Figure 2-2, the length of an asbestos fiber may range from less than 0.1 micrometer to several tens of micrometers. As previously discussed, individual fibrils can be as thin as 0.02 µm. The extremely small size of asbestos fibers indicates two significant fiber characteristics: aerodynamic transport potential and respirability.

Based on Stokes' Law, an airborne fiber will settle downward at a rate determined by its mass, shape, size, and axis attitude. Fiber settling velocity is strongly dependent upon fiber diameter and to a lesser extent upon fiber length. Fibers with diameters smaller than 1 µm can remain airborne for several hours, and fibers with diameters smaller than 0.1 µm can remain airborne for several days or weeks. Turbulence (such as the air flow around a moving vehicle) and wind velocity will prolong settling time and increase the distance traveled by airborne fibers. Fibers which remain airborne the longest have the greatest potential to be inhaled.

---

*1 ng = 10^{-9} grams.

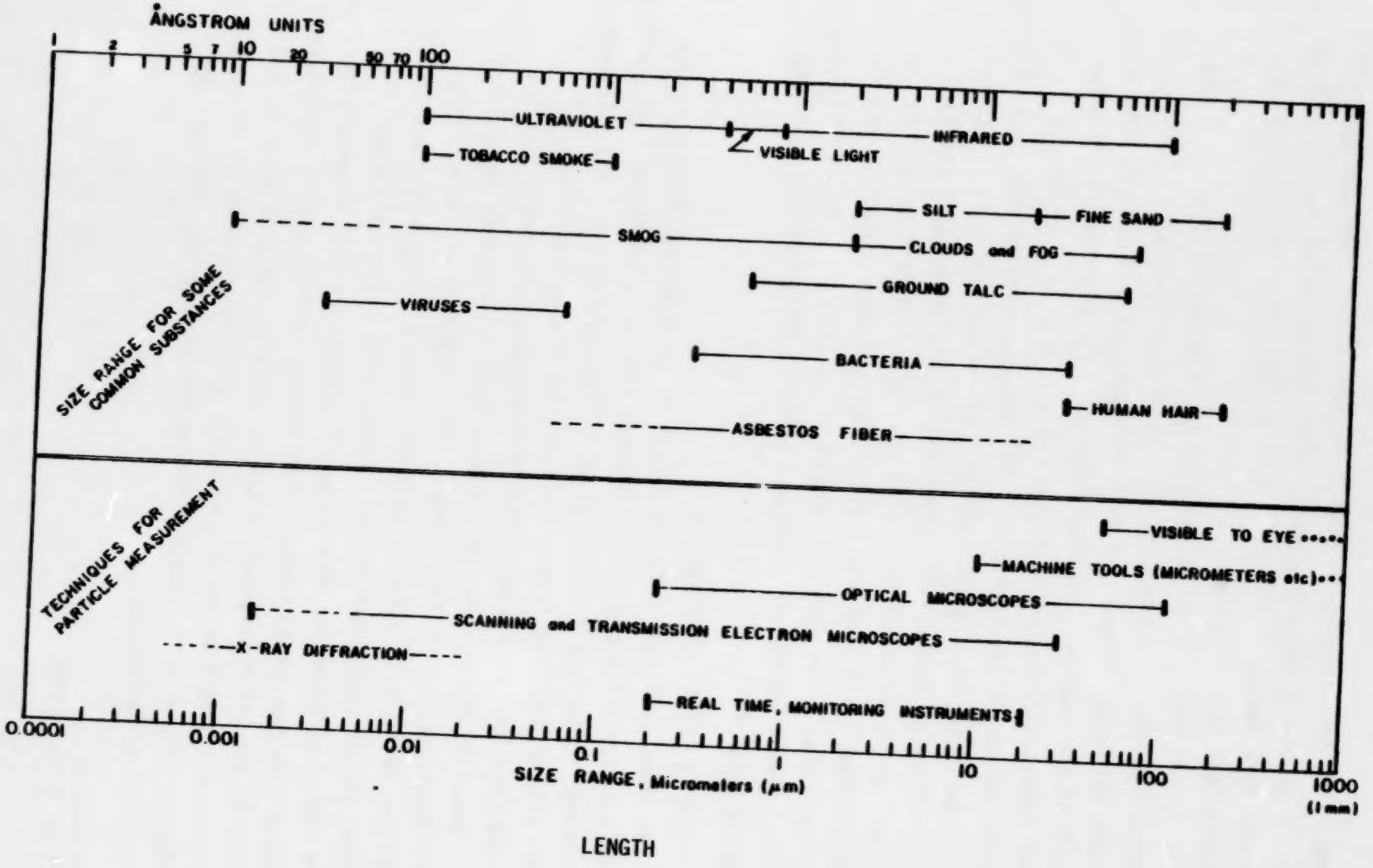


Figure 2-2. Comparison of asbestos fibers and other particles by size and measurement techniques.[11]

Inhalable particles, particles with diameters smaller than 10 µm, can be deposited on air passage surfaces all along the respiratory tract. Fine particles (smaller than 2 µm) are of greater biological significance than larger particles because they are more likely to be deposited in the alveolar region of the lung.[12]

2.6 HUMAN HEALTH EFFECTS ASSOCIATED WITH INHALATION OF ASBESTOS

2.6.1 Introduction

Exposure to asbestos is associated with increased risks of many diseases, including pulmonary fibrosis (asbestosis), respiratory cancer, and mesothelioma of both pleural and peritoneal tissue. These health effects have been documented in over 90 studies conducted by many researchers using different groups of occupational workers. (See reference 13 for a listing of these studies and their principal findings.) For the purposes of this document, the health effects discussion will focus on studies that investigated a quantitative dose-response relationship for disease among workers exposed to only chrysotile asbestos, studies of asbestos-related health effects resulting from nonoccupational exposure, and studies that investigated the influence of cofactors such as smoking habits and age.

2.6.2 Health Hazards of Chrysotile Exposure

2.6.2.1 Asbestosis Mortality. Asbestosis is a chronic, noncancerous, irreversible disease characterized by hardening and thickening of lung tissue. Asbestosis has been a major cause of death in groups of workers exposed to high levels of airborne asbestos. Asbestosis is a progressive disease that can continue to develop long after a person has been removed from the source of exposure. Several occupational studies have demonstrated dose-response relationships between exposure to asbestos and severity of asbestosis. The dose-response curve for asbestosis mortality among Canadian chrysotile miners and millers has been described by McDonald (1979) as a linear relationship, although the author cautions against extrapolation to very low exposure levels.[14]

2.6.2.2 Lung Cancer Mortality. Many epidemiological studies have clearly demonstrated that the risk of lung cancer is increased by exposure to asbestos. Few researchers, however, have attempted to quantify the risk because of problems in estimating cumulative exposure. Three recent studies, McDonald (1980), Enterline and Henderson (1979), and Dement et al. (1980), have investigated a quantitative dose-response relationship for lung cancer among workers exposed to only chrysotile.[15-17] All three studies suggest that the relationship between cumulative dust exposure and lung cancer is linear, i.e., the risk of lung cancer is directly proportional to cumulative exposure. The authors disagree on the magnitude of increased risk for a given cumulative exposure, particularly for those workers in the lowest exposure categories. Differences in study design and the method of exposure estimation probably account for some of the inconsistencies in the findings of these three studies.

McDonald (1980), who studied chrysotile miners and millers in Quebec, and Enterline (1979), who investigated mortality of retired maintenance-service employees of an asbestos manufacturing company, estimated past dust exposure using work histories and total airborne particulate data collected by the impinger method.* McDonald included persons exposed to extremely high airborne fiber levels, thus competing risk (i.e., persons dying from other causes) may be a problem. Enterline's study group consisted only of retirees older than 65 years of age and may represent a survivor population with less lung cancer risk than the general public. Workers who died before their 65th birthday were not included in the study. Both McDonald and Enterline found that the risk of respiratory malignancies increases directly with increasing cumulative exposure but that an excess risk is difficult to detect in the groups with least exposure.

Dement (1980), who studied mortality among chrysotile textile workers, used asbestos fiber count data (determined by phase contrast microscopy) to estimate past exposure. Conditions at the textile plant allowed Dement to evaluate health effects at exposure levels lower than the levels measured by McDonald or Enterline. Dement's data suggest a linear dose-response relationship with no threshold for lung cancer and nonmalignant respiratory diseases. Lung cancer demonstrated a statistically significant excess in even the lowest cumulative exposure category. The risk of lung cancer at a given cumulative dose was also found to be greater than the risk reported by McDonald and Enterline.

---

*The impinger method involves pulling a volume of air through a small tube containing water or alcohol. Particles that settle in the tube are examined by light microsopy. The impinger method was replaced by the membrane filter technique in 1971 for determining occupational exposure to asbestos.

2.6.2.3 Pleural and Peritoneal Mesothelioma. Researchers have shown that exposure to asbestos can produce mesothelioma of the pleura (the membrane that surrounds the lungs and lines the thorax) and/or the peritoneum (the membrane that surrounds the abdominal organs and lines the abdominal and pelvic cavity). Estimated incidence of mesothelioma in the United States and Canada ranges from one to six cases per million population and in general, seem to be higher in cities where asbestos has been used in the shipbuilding or ship repair industries.[18] The disease is often not detected for 30 to 40 years after initial exposure.

The three studies that quantitatively estimated exposure and lung cancer among chrysotile workers found low mortality due to mesothelioma; Dement (1980) found 1 death, McDonald (1980) found 11 deaths, and Enterline (1979) found 1 death. In another study, Robinson et al. (1979) observed 17 mesotheliomas among 1,040 deaths in a plant using predominantly chrysotile; however, some crocidolite and amosite were used at the plant.[19]

Epidemiologists agree that mesothelioma is generally underdiagnosed, and the proper study of the incidence of this disease requires information in addition to that which ordinarily appears on death certificates.[16]

2.6.3 Nonoccupational Exposure to Asbestos

Perhaps the most disconcerting aspect of the relationship between mesothelioma and asbestos exposure is the documented association of the disease with apparently low levels of exposure for relatively brief periods from neighborhood or domestic sources.[20] In 1960, Wagner documented cases of mesothelioma in residents of an asbestos mining area of South Africa. Many of these individuals had never worked with asbestos; their exposure was associated with living near the mines, mills, or roadways along which the asbestos fiber was transported.[21] In 1964, Newhouse and Thompson reviewed 76 cases of reported mesothelioma in London. Roughly half were found to be former employees of an asbestos manufacturing facility, 11 were individuals who lived within 1/2 mile of the asbestos factory, and 9 were individuals who lived with workmen employed at the factory.[22]

More recently, Borow et al. (1973), using hospital records rather than plant records, reported 72 cases of mesothelioma in the vicinity of one of the two plants studied by Enterline.[23] Upon further investigation 41 of these cases were found to have worked at the plant at some time. Many of these cases died before the age of 65 and thus were excluded from Enterline's study groups. Anderson et al. (1976) examined 378 family members of asbestos workers 25-30 years after the onset of initial asbestos exposure. Of these, 239 were found to have one or more chest abnormalities. Five cases of mesothelioma were found in the study group.[24] In a case-control study of all female residents of New York State who died of mesothelioma between 1967 and 1977, Vianna (1978) found that 15 of 62 confirmed cases had worked in asbestos-related industries and 10 had husbands or fathers that worked in asbestos related industries.[25]

Several researchers have shown that asbestos-related diseases are endemic in some villages in Turkey. Baris (1975) studied 120 cases of pleural disease (108 of these were malignant mesothelioma) and found only 2 cases with occupational exposure to asbestos. Of the other 118 cases, 16 cases had a history of environmental exposure to asbestos. No condition that may result in the inhalation of asbestos was encountered in the rest of the cases. In such cases, it was suggested that the disease may result from the ingestion of water, beverages, or food, or from other sources.[26]

Yazicouglu (1976) investigated the occurrence of pleural calcifications (an early stage of asbestosis, from which mesothelioma may also develop) in the inhabitants of several towns located in areas of naturally occurring chrysotile in southeast Turkey. No industrial source of asbestos is located in the area. A total of 389 individuals (2.6 percent of the total population) showed pleural calcifications upon examination.[27]

2.6.4 Factors That Modify the Risk of Asbestos Induced Disease

2.6.4.1 Smoking Habits. The major factor affecting the risk of asbestos-induced lung cancer, other than the intensity and duration of the exposure itself, is the smoking habit of the exposed individual. The effects of asbestos exposure and cigarette smoke are multiplicative, not simply additive (Selikoff et al., 1980).[28] Stopping cigarette smoking is likely to be of paramount importance in reducing the excess cancer risks in asbestos-exposed individuals (Gilson, 1976).[29]

The current consensus of the scientific community is that mesothelioma occurs with equal frequency among smoking and nonsmoking asbestos workers. Available studies of asbestos workers are inadequate to determine whether smoking increases the risk of developing asbestosis.

2.6.4.2 Age. Children exposed to asbestos have a greater lifelong risk than adults equally exposed. This can be a significant factor when long latency periods are encountered for diseases such as lung cancer and mesothelioma. The question of susceptibility has been raised by some researchers. Kotin (1977) and Wasserman et al. (1979) suggest that children are more susceptible than adults to carcinogens, including asbestos.[30] [31] Other researchers (Doll, 1962; Cole, 1977) state that special biological susceptibility has not been demonstrated for children exposed to asbestos.[32] [33]

2.6.5 Fiber Characteristics

2.6.5.1 Fiber Size. A great deal of research has investigated variations in risk posed by fibers differing in size and chemical composition. The potential adverse health effects of long fibers (>5 μm in length) versus short fibers (<5 μm in length) is currently a topic of debate. So far nothing is known about the importance of fiber size in the production of bronchial tumors.[29] The primary research relating fiber size to carcinogenic potency applies only to pleural mesothelioma and involves the direct injection or implantation of fibers into the pleura of rats. Some evidence suggests that fibers may have to be ≥10 μm in length and less than about 1 μm in diameter in order to produce mesothelioma.[29] Pott (1978), however, states that fibers as short as 3 μm in length have carcinogenic potency.[34] Selikoff believes that fibers less than 3 μm in length can produce tumors. Gross (1974) disagrees with his colleagues and believes that fibers <5 μm in length are devoid of carcinogenic potency.[35] Stanton and Layard (1977) investigated the carcinogenicities of 37 different dimensional distributions of seven fibrous materials and attained optimum correlation with fibers that measured less than 0.25 μm in diameter and greater than 8 μm in length.[36]

The authors did not state that fiber sizes outside this optimal range were devoid of carcinogenic potency.

Presently there is no firm conclusion concerning the relative activities of short and long fibers. It cannot be said with any confidence that fibrogenicity drops to negligible proportions at 5 μm or 1 μm.[37] Pott (1978) states that even if the carcinogenic potential of a relatively short fiber may be weak, many short fibers may induce a tumor as easily as a few large fibers. The author goes on to say that special problems arise in calculating carcinogenic potency when bundles of asbestos fibers are encountered. The possibility of an asbestos fiber bundle splitting when inhaled can easily increase carcinogenic potency.

2.6.5.2 Fiber Type. Human occupational exposures to all commercial asbestos fiber types, both individually and in various combinations, have been associated with high rates of asbestosis, lung cancer, and mesothelioma. Presently available information indicates that the incidence of lung cancer does not depend on the type of fiber but mainly on the dose level. The incidence of mesothelioma appears to be linked to the type of asbestos.[18] There is general agreement that the risk of mesothelioma is fiber related in the order:

crocidolite > amosite > chrysotile > anthophyllite

The magnitude of the difference between, for example, crocidolite and chrysotile is not well understood. Timbrell (1973) states that chrysotile fibers normally are not observed near the pleura because of their curved shape; however, short chrysotile fibers may behave like crocidolite and penetrate into deeper regions of the respiratory system.[38]

2.6.6 Summary of Health Effects

Inhalation of asbestos is known to cause asbestosis, lung cancer, and mesothelioma in humans. Our knowledge of the carcinogenic effects of asbestos is almost entirely derived from occupational studies. Recent studies of chrysotile workers that relied on older methods (i.e., impingers) of estimating dust exposure support the linear dose-response hypothesis for lung cancer among most exposure groups. The most recent study of chrysotile workers (Dement et al., 1980) estimated exposure to airborne asbestos fiber concentrations using phase contrast microscopy and indicated that there is no threshold to the linear relationship for lung cancer and nonmalignant respiratory diseases. The evidence of asbestos-related disease in members of asbestos-worker households and in persons living near asbestos-contaminated areas lends additional support to the no-threshold, linear dose-response hypothesis.

Smoking habits and age are two important cofactors associated with increased risk of asbestos-related disease. Currently, there is no consensus among researchers as to the relative carcinogenic potency of short versus long fibers. The varying intensity and type of exposure, the problem of exposure estimation, and the influence of cofactors make it extremely difficult to specify safe exposure levels for the general public. Consequently, EPA believes that public exposure to airborne asbestos be reduced to the greatest extent practical.

2.7 REFERENCES FOR CHAPTER 2

1. Control Techniques for Asbestos Air Pollutants. Publication AP-117. U.S. Environmental Protection Agency. Research Triangle Park, N.C. February 1973.

2. Letter from Forshey, D. R., U.S. Bureau of Mines, to Goodwin, D. R., EPA. April 9, 1981. p. 5. Response to Working Group mailout.

3. Levine, R. J. Asbestos: An Information Resource. National Cancer Institute. Bethesda, Md. PB-293-736. May 1978. 150 p.

4. Workplace Exposure to Asbestos: Review and Recommendations. NIOSH-OSHA Asbestos Work Group. April 1980. 62 p.

5. Electron Microscopic Measurement of Airborne Asbestos Concentrations--A Provisional Methodology Manual. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA 600/2-77-178. Revised June 1978. 48 p.

6. Evaluating and Optimizing the Electron Microscope Method for Characterizing Airborne Asbestos. U.S. Environmental Protection Agency. Research Triangle Park, N.C. EPA 600/2-78-038. June 1978. 182 p.

7. Miller, J. L. Identification of Selected Silicate Minerals and Their Asbestiform Varieties by Electron Optical and X-Ray Techniques. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA 600/J-78-136. December 1978. 12 p.

8. Memorandum from Scaringelli, R., EPA:ESAS to Chief, EPA:SDB. January 8, 1974. p. 7. Concentration of Asbestos in United States cities.

9. Asbestos Contamination of the Air in Public Buildings. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-450/3-76-004. October 1975.

10. Bruckman, L. and R. Rubino. Asbestos: Rationale Behind a Proposed Air Quality Standard. APCA Journal. 25:1207-1215. December 1975.

11. Asbestos-Containing Materials in School Buildings. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-450/2-78-014. March 1979.

12. Lippmann, M. Inhalation, Deposit and Clearance of Particles. New York University Institute of Environmental Medicine. New York, New York. (Presented at the proceedings of the National Workshop on Substitutes for Asbestos. July 14-16, 1980). U.S. Environmental Protection Agency. Washington D. C. Publication No. EPA 560/3-80-001. November 1980. pp. 283-312.

13. Revised Recommended Asbestos Standard. U.S. National Institute of Occupational Safety and Health (NIOSH). Washington, D. C. December 1976. pp. 53-57.

14. McDonald, J. C., and F. D. Kiddell. Mortality in Canadian Miners and Millers Exposed to Chrysotile. Annals of the New York Academy of Science. 330:1-9. 1979.

15. McDonald, J. C., et al. Dust Exposure and Mortality in Chrysotile Mining. British Journal of Industrial Medicine. 37:11-24. 1980.

16. Henderson V., and P.E. Enterline. Asbestos Exposure: Factors Associated With Excess Cancer and Respiratory Disease Mortality. Annals New York Academy of Sciences. pp. 117-125. 1979.

17. Dement, J. M., R. L. Harris, M. J. Symons, and C. Shy. Estimates of Dose-Response For Respiratory Cancer Among Chrysotile Asbestos Textile Workers. (Presented at the Fifth International Symposium on Inhalable Particles and Vapors. Cardiff, Wales. September 1980). pp. 10.4-1 thru 10.4-23.

18. Zielhuis, R. L. Public Health Risks of Exposure to Asbestos. Report of a Working Group of Experts Prepared for the Commission of the European Communities. Directorate-General for Social Affairs, Health and Safety Directorate. Luxembourg, Pergamon Press. 1977. 143 p.

19. Robinson, et al. Mortality Patterns, 1940-1975 Among Workers Employed in an Asbestos Textile, Friction, and Packing Products Manufacturing Facility. In: Dust and Diseases, Lemen R.A., and Dement, J. M., (eds.) Park Forest South, Illinois, Pathatox Publishers Inc., 1979. 131 p.

20. Becklake, M. R. Asbestos Related Diseases of the Lung and Other Organs: Their Epidemiology and Implications for Clinical Practices. American Review of Respiratory Disease. 114:210. 1976.

21. Wagner, I. C., C. A. Sleggs, and P. Marchand. Diffuse Pleural Mesothelioma and Asbestos Exposure in North Western Cape Province. British Journal of Industrial Medicine. 17:260-271. 1960.

22. Newhouse, M. L. and H. Thompson. Mesothelioma of Pleura and Peritoneum Following Exposure to Asbestos in the London Area. British Journal of Industrial Medicine. 22:261-269. 1965.

23. Borow, M. A., et al. Mesothelioma Following Exposure to Asbestos: A Review of 72 Cases. Chest. 64:641-646. 1973.

24. Anderson, H. R., et al. Household Contact Asbestos Neoplastic Risk. Annals of the New York Academy of Science. 271:311-323. 1976.

25. Vianna, N. J. and A. K. Polan. Non-occupational Exposure to Asbestos and Malignant Mesotheliomas in Females. Lancet. 1:1061. 1978.

26. Baris, Y.I. Pleural Mesotheliomas and Asbestos Pleurisies Due to Environmental Asbestos Exposure in Turkey: An Analysis of 120 Cases. Hacettepe Bulletin of Medicine. Vol. 8, No. 4. pp. 165-185. December 1975.

27. Yazialoglu S. Pleural Calcification Associated with Exposure to Chrysotile Asbestos in Southeast Turkey. Chest. 70:43-47. July 1976.

28. Selikoff, et al. Mortality Effects of Cigarette Smoking Among Amosite Factory Workers. Journal of National Cancer Institute. 65:507-513. 1980.

29. Gilson, J. C. Asbestos Cancers as an Example of the Problem of Comparative Risk. INSERM. 55:107-166. 1976.

30. Kotin, P. Briefing Before the Consumer Product Safety Commission. 22 FR 38786. July 29, 1977.

31. Wassermann, M., et al. Mesothelioma in Children. (Presented at the Symposium on the Biological Effects of Mineral Fibers. Lyon, France. September 25-27, 1979.)

32. Doll, R. Susceptibility to Carcinogenicities at Different Ages. Geron Clin. 4:211-221. 1962.

33. Cole, P. Cancer and Occupation. Cancer. 39:1788-1791. 1977.

34. Pott, F. Some Aspects of the Dosimetry of the Carcinogenic Potency of Asbestos and Other Fibrous Dust. Staub-Reinhalt Luft. 12:486-490. December 1978.

35. Gross, P. Is Short-Fibered Asbestos Dust a Biological Hazard? Archives of Environmental Health. 29:115-117. August 1974.

36. Stanton, M. and M. Layard. The Carcinogenicity of Fibrous Minerals NIOSH. Bethesda, Maryland. (Presented at Proceedings of the Workshop on Asbestos: Definitions and Measurement Methods. Gaithersburg, Maryland, July 18-20, 1977). pp. 143-151.

37. Selikoff, I. and D. Lee. Asbestos and Disease. Academic Press. 1978. p. 428.

38. Timbrell, V. Physical Factors as Etiological Mechanisms. Biological Effects of Asbestos. Lyon, France. IARC. p. 295. 1975.

3. EXPOSURE ASSESSMENT FOR CRUSHED STONE CONTAINING CHRYSOTILE

3.1 DETECTION OF ASBESTOS EMISSIONS IN MARYLAND IN 1976

In September 1976, asbestos was identified as a component of the crushed stone used to surface many unpaved roads in Montgomery County, Maryland. The source of the crushed stone was a quarry in Rockville, Maryland, located in a serpentinite rock deposit. Atmospheric particulate samples collected near an unpaved road surfaced with crushed serpentinite were analyzed with an electron microscope and showed chrysotile mass concentrations about 1,000 times greater than those typically found in urban air.[1] Dust collected from the quarry's stockpile and a nearby road contained from 0.1 to 0.7 percent chrysotile by weight.[2]

Several air monitoring programs were conducted in 1976 and 1977 by the State of Maryland, the Montgomery County DEP, and EPA to measure airborne chrysotile concentrations in Montgomery County associated with different uses of crushed serpentinite and to evaluate various EM preparation and analysis procedures used by different laboratories.[3-7] EPA concluded from the test data that:

1. Uses of serpentinite that result in the generation of visible dust also result in elevated asbestos levels;
2. All laboratories should use the same EM preparation and analysis procedures for determining airborne asbestos concentrations; and
3. The particular quarry in question was not a major source of airborne asbestos in the vicinity.

Upon consideration of these conclusions and supplementary analyses by EPA personnel, the Agency recommended that the State of Maryland and Montgomery County DEP act to control chrysotile emissions from unpaved roads surfaced with serpentinite. The State and County responded by paving all such roads (92 miles) in the county. In addition, crushed serpentinite used in parks and playgrounds was removed or covered.

Montgomery County DEP conducted additional air monitoring of the following sources in 1977-1978 to assess asbestos emissions from other uses of crushed sepentinite: a lightly traveled unpaved road, an unpaved road treated with a dust suppressant, driveways, playgrounds, unpaved parking lots, and residential paved roads. Asbestos fiber concentrations ranged from 0.002 to 3.3 fibers/ml.[8] From the site-specific results, Montgomery County DEP concluded that "elevated asbestos levels occurred only on unpaved road surfaces or bare stone surfaces with moderate-to-heavy vehicular traffic creating dust conditions."[8] The terms "elevated asbestos levels" and "moderate-to-heavy vehicular traffic" were not defined in the report.

3.2 NATIONWIDE INVESTIGATION OF CHRYSOTILE EMISSIONS FROM ROADWAYS AND QUARRIES

3.2.1 Advanced Notice of Proposed Rulemaking

In the summer of 1977, EPA requested assistance from the Bureau of Mines (BOM), the United States Geological Survey (USGS), and the Mining Enforcement and Safety Administration (MESA)* to determine the extent to which quarrying operations were being conducted nationwide in asbestos-containing rock deposits. MESA initiated a long-term study to identify mining operations with asbestos emissions that exceed the present MSHA standard for airborne asbestos (see Appendix A, Table A-3). MSHA's investigation, which includes several thousand mining operations located in metamorphic rock deposits, has not yet been completed.

EPA's survey of the crushed stone industry concentrated on quarries located in serpentinite rock deposits because these deposits are known to contain chrysotile. On November 10, 1977, EPA published an Advance Notice of Proposed Rulemaking (42 FR 58543) stating that a standard regulating the production and use of serpentinite rock would be proposed if the Agency determined that the production and use of such stone causes asbestos emissions proximate to the public in a number of locations.

---

*MESA was renamed the Mine Safety and Health Administration (MSHA) when the agency was transferred from the Department of Interior to the Department of Labor pursuant to the Federal Mine Safety and Health Amendments Act of 1977.

3.2.2 EPA Quarry Survey

Serpentinite rock deposits occur throughout much of the Appalachian Mountains and in some portions of the Western coastal ranges. A list of the 23 States that have known serpentinite deposits is shown in Table 3-1. Quarries located in serpentinite deposits were identified by transparent map overlays that "matched" known quarry locations with known deposits of serpentinite. Maps showing serpentinite rock deposits in the United States were prepared by the USGS for this purpose. BOM provided map overlays (of the same scale) that indicated quarry locations. Supplemental information on quarry locations was supplied by the State Aggregate Association and EPA's National Emissions Data System (NEDS). Quarries located within a 10-mile radius of a known serpentinite deposit or located in a strata of rock between known serpentinite deposits were considered to be potential sources of chrysotile.[9] EPA requested that State geologists review the mapping procedure for locating potential sources of chrysotile within their respective States and provide information about specific quarries identified by the mapping procedure. State geologists confirmed that 8 quarries positively produce crushed serpentinite containing chrysotile and suspected that 111 other quarries may be producing this material.[10-13] Petrographic analysis of rock samples from the 111 suspect quarries identified 8 additional quarries that contain chrysotile.[14] A list of the 16 quarries producing crushed serpentinite and the range of chrysotile concentration in their product are shown in Table 3-2.

Field investigations determined that only 5 of the 16 quarries in Table 3-2 produce crushed serpentinite which is used for surfacing unpaved public roads.[16-21] The five quarries are listed in Table 3-3 along with the number of road miles surfaced with serpentinite and the estimated number of nearby residents. Approximately 400 miles of public roads in four States are surfaced with crushed serpentinite (predominantly from three of the five quarries). Approximately 6,500 people nationwide reside within approximately 200 feet of these roads and are the persons most likely to be exposed to chrysotile emissions from the roadways. Population figures were estimated from county maps and field surveys.

EPA conducted an additional field investigation of Federal lands and found that the USFS and the Bureau of Land Management (BLM) operate a

TABLE 3-1. STATES WHERE DEPOSITS OF SERPENTINITE ROCK OCCUR

Alabama
Alaska
Arizona
California
Connecticut
Georgia
Idaho
Maine
Maryland
Massachusetts
Montana
Nevada
New Hampshire
New Jersey
New York
North Carolina
Oregon
Pennsylvania
Rhode Island
South Carolina
Vermont
Virginia
Washington

TABLE 3-2. QUARRIES PRODUCING CRUSHED SERPENTINITE CONTAINING CHRYSOTILE CONFIRMED THROUGH PETROGRAPHIC AND/OR EM ANALYSIS OF STONE PRODUCT[2] [15] [22]

Quarry name	Location County	 State	Chrysotile concentration percent weight[a]	Ownership
Azevedo	Santa Clara	California	0.50-1.60	Private
Bluemont	Baltimore	Maryland	b	Private
Cedar Hill	Lancaster	Pennsylvania	0.30-2.40	Private
Delight	Baltimore	Maryland	0.05-0.40	Private
Dumbarton	Alameda	California	b	Private
Ghilotti Brothers	Marin	California	0.10-1.40	Private
Hillsdale	Santa Clara	California	0.20-2.70	Private
Rockville	Montgomery	Maryland	0.03-0.70	Private
Cardinal	Grayson	Virginia	0.02-1.2	Private
George Reid	Tuolumne	California	b	Private
Woods Creek	Tuolumne	California	0.01-0.70	Private
Morris Pit	Coos	Oregon	b	Private
Six Bits (Red Hill)	Tuolomne	California	b	Tuolumne County
Chancellor Pit	Josephine	Oregon	b	Oregon State
(Unnamed)	Jackson (Section 11, Township 34 South, Range 4 West)	Oregon	b	BLM
(Unnamed)	Josephine (Section 29, Township 36 South, Range 7 West, Siskayou National Forest)	Oregon	b	USFS

---

[a] Determined by electron microscopy.

[b] The presence of chrysotile was qualitatively determined by petrographic analysis. No quantitative data are available.

TABLE 3-3. UNPAVED ROADS SURFACED WITH QUARRIED SERPENTINITE AND THE ESTIMATED NUMBER OF NEARBY RESIDENTS[a] [b]

Quarry	Counties where serpentinite is used for surfacing unpaved roads	Miles of unpaved roads surfaced with serpentinite	Estimated No. of nearby residents
Bluemont	Baltimore County, Md.[c]	16	650
Cedar Hills	Harford County, Md.	64	2,750
Cardinal	Grayson County, Va.	100	1,200
	Alleghany County, N.C.	220	1,700
Woods Creek	Tuolumne County, Calif.	2	20
Six Bits	Tuolumne County, Calif.	3	30
Total		405	6,350

[a] Nearby residents are those people whose homes are located within approximately 200 ft of a serpentinite-surfaced road.

[b] In 1978 and 1979 the Montgomery County Department of Transportation paved all county roads (92 miles) surfaced with crushed serpentinite. The number of nearby residents was not estimated.

[c] Baltimore County plans to hard-surface these roads in 1981.

number of small quarries in areas of California and Oregon where serpentinite deposits are common. These quarries produce stone to maintain logging roads on Federal land that are used by haul vehicles during intermittent harvest seasons. In the general vicinity of these quarries there are roughly 1,000 miles of native stone/soil roads over serpentinite outcroppings that are not surfaced with quarry material. A massive outcropping of serpentinite is known to occur in San Benito County, California, where BLM maintains the 43,000 acre Clear Creek Federal Recreation Area. Clear Creek had over 41,000 users in 1975, 85 percent of which were operators of off-road vehicles.[23] Serpentinite data concerning Federal lands are shown in Table 3-4.

BLM, USFS, and the Department of Interior are conducting investigations to determine the occurrence and use of serpentinite on additional Federal lands. In response to the known data, the USFS has announced that asbestos sampling will be conducted in 1981 at quarry sites and adjacent roads in several of the National Forests listed in Table 3-4. The BLM regional office in Sacramento, California, is preparing an environmental assessment report for the Clear Creek Recreation Area and will hold public hearings in 1981 to discuss management alternatives for the popular recreation area.

3.3 ASBESTOS SAMPLING, 1979

EPA conducted an extensive air monitoring program in 1979 to measure chrysotile emissions that result from the production and use of crushed serpentinite and to characterize the variables that influence those emissions. Data from the monitoring program were used to evaluate the performance of the provisional method for electron microscope measurement of asbestos concentrations in ambient air.

Air monitoring was conducted at six sites:

1. Holy Cross Road, Harford County, Maryland;
2. McNabb Road, Harford County, Maryland;
3. Cedar Hills Quarry, Lancaster County, Pennsylvania;
4. Woods Creek Quarry, Tuolumne County, California;
5. Duffy Road, Tuolumne County, California; and
6. Clear Creek Federal Recreation Area, San Benito County, California.

TABLE 3-4. SERPENTINITE QUARRIES AND UNPAVED ROADS LOCATED ON FEDERAL LANDS[19, 24]

Location	Quarries on Federal land producing serpentinite	Miles of unpaved roads surfaced with quarried serpentinite[a]	Miles of roads over native serpentinite outcroppings
Klamath National Forest (NF) California	3	65	390
Six Rivers NF California	4	180	380
Shasta-Trinity NF California	2	28	0
Mendocino NF California	1	40	42
Tahoe NF California	1	0	0
Los Padres NF California	0	0	0
Plumas NF California	0	0	60
BLM-Medford District Oregon	20-30	NA[b]	NA
BLM-Clear Creek Recreation Area California	0	0	c

[a] Unpaved roads in National forests are primarily used by haul vehicles during intermittent harvesting operations.

[b] NA = not available.

[c] Much of this 43,000-acre recreation area is located in serpentinite outcroppings and is used by off-road-vehicles.

Airborne particulate samples were collected in the vicinity of Cedar Hills Quarry and Woods Creek Quarry to determine ambient chrysotile concentrations that result from the production of crushed serpentinite. Data from the Holy Cross Road site and the McNabb Road site were used to assess the airborne chrysotile concentrations to which local residents may be exposed and to characterize the variables that influence chrysotile emissions from roadways. Both roads are surfaced with crushed serpentinite produced by the Cedar Hills Quarry. Air sampling was conducted in the Clear Creek Recreation Area to measure ambient chrysotile concentrations to which visitors may be exposed.

A summary report of the monitoring program is contained in Appendix B. The program's major conclusions are summarized below.

3.3.1 Conclusions

1. Statistical evaluation of the results indicate that ambient chrysotile fiber concentrations can be measured with an acceptable degree of precision. The coefficient of variation for intra- and interlaboratory analysis of split and colocated samples ranged from 34 percent to 72 percent (see Table B-19).

2. Analyses indicate that airborne chrysotile fiber concentrations downwind of unpaved roads surfaced with crushed serpentinite, containing trace amounts of chrysotile and subject to light-to-moderate traffic, are significantly higher than concentrations upwind of those roads. The geometric mean for 16 upwind samples from the unpaved roads in Harford County, Maryland, was 0.16 fiber/ml. Chrysotile fiber concentrations measured at different distances downwind of the roadways ranged from 0.04 to 2.52 fibers/ml. These downwind concentrations resulted after approximately 30 vehicle passes (at 30 mph) were made across the dry, unpaved road surfaces during a 2-hour sampling period.

3. No statistically significant relationship was found for fiber concentrations versus receptor distance downwind, chrysotile content of the roadstone, traffic volume, or wind speed. No conclusions can be drawn concerning the influence of these variables on chrysotile emissions from roadways.

4. Results support the conclusion made earlier by the Montgomery County DEP that serpentinite quarries are not a major source of airborne

asbestos to the surrounding area. Chrysotile concentrations measured near two serpentinite quarries ranged from 0.01 to 0.35 fiber/ml with a geometric average of 0.04 fiber/ml.

5. The chrysotile concentrations reported in this study underestimate the true potential for asbestos exposure from unpaved roads surfaced with serpentinite. TEM analysis revealed that many of the particulate samples contained bundles and sheaves of fibers that have the potential to split into many fibrils. The reported fiber concentrations are based only upon the observable fibers with length-to-width ratio of 3 or greater. Numerous fibers may eventually be released from a single bundle of fibers. Also, chrysotile fibers that were obscurred by the presence of other material on the filter preparations could not be counted.

6. Fiber concentrations reported in this study are not comparable to fiber concentrations determined by phase-contrast microscopy. Nearly all the fibers detected were short, thin fibers (less than 5 μm in length and less than 0.1 μm in diameter) that would not be counted by phase contrast microscopy because of procedural and analytical limitations.

7. Chrysotile fiber concentrations near campsites in the Clear Creek Recreational Area are approximately 100 times greater than average ambient background concentrations observed at the test sites located in Harford County, Maryland.

3.4 EPA RESPONSE TO ADVANCE NOTICE OF PROPOSED RULEMAKING (42 FR 58543)

Monitoring studies indicate that serpentinite quarries are not a major source of airborne asbestos to the surrounding area. However, the use of serpentinite to surface unpaved roads results in local chrysotile concentrations significantly higher than background levels. From a nationwide survey of the quarry industry, it has been determined that quarried serpentinite is used to maintain a small number of unpaved public roads in a few locations in the United States. Approximately 6,500 people are likely to be exposed to chrysotile emissions from these roads.

EPA believes that asbestos emissions from unpaved roads and other dusty sources (such as unpaved parking lots) should be reduced to the greatest extent practical. The level of asbestos emissions as well as the most appropriate method to control those emissions varies with location. EPA has concluded that local, State, and Federal agencies that maintain these roads are in the best position to assess local conditions and implement the most appropriate control measures.

3.5 REFERENCES FOR CHAPTER 3

1. Rohl A. M., A. M. Langer, and I. J. Selikoff. Environmental Asbestos Pollution Relating to Use of Quarried Serpentinite Rock. Science. 9:1319-1322. June 17, 1977.

2. Memorandum from Miller, J. L., EPA:ESRL to Roy, S. L., EPA:ESED. April 11, 1977. p. 2. Quantitative measurement of asbestos (chrysotile) in Rockville, Maryland quarry sample.

3. Sampling data presented at the Asbestos Meeting of the National Institute of Health. June 8, 1977.

4. Letter and attachments from Cooney, W. W., Maryland Department of Health and Mental Hygiene, to Fitzgerald, D., EPA. February 25, 1977. Transmittal of Maryland sampling results for 22 air filters.

5. Analysis of Ten Filter Samples From State of Maryland Department of Health and Mental Hygiene: Rockville Quarry. Walter C. McCrone Associates, Inc. Chicago, Illinois. June 1977.

6. Comparison of Ambient Asbestos Levels Determined by Various Laboratories. U.S. Environmental Protection Agency. Research Triangle Park, N.C. September 1977.

7. Montgomery County Asbestos Study. U.S. Environmental Protection Agency. Research Triangle Park, N.C. October 1977.

8. Asbestos in the Environment of Montgomery County, Maryland, 1981. Division of Pollution Control, Montgomery County Department of Environmental Protection. Rockville, Maryland. February 1981.

9. Procedure for Identification of Rock Quarries That Contain Asbestos. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA 450/3-78-032. July 1978.

10. Letter from Gay, T. E., Jr., California Division of Mines and Geology, to Goodwin, D. R., EPA. October 13, 1977. Response to request to identify California quarries located in serpentinite rock deposits.

11. Letter from Beaulieu, J. D., Oregon Department of Geology and Mineral Industries, to Goodwin, D. R., EPA. December 5, 1977. Response to request to identify Oregon quarries located in serpentinite rock deposits.

12. Letter from Weaver, K. N., Maryland Geological Survey, to Goodwin, D. R., EPA. February 1, 1978. Response to request to identify Maryland quarries located in serpentinite rock deposits.

13. Letter from Wheatly, L. F., Virginia Department of Labor and Industry, Division of Mines and Quarries, to Fitzgerald, D. J., EPA. April 24, 1978. Response to request to identify Virginia quarries located in serpentinite rock deposits.

14. Asbestos Rock Quarries--Mineralogical Analysis of Crushed Stone Samples. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA 450/3-79-031. July 1979. 155 p.

15. Asbestos Analyses of Crushed Stone Samples. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-450/3-80-039. April, 1981. 378 p.

16. Memo from Mumma, C. E., Midwest Research Institute, to Wood, G. H., EPA. March 12, 1979. Trip report for visit to Baltimore and Montgomery County, Maryland, to identify roads surfaced with serpentinite.

17. Memo from Warner, R. A., Midwest Research Institute, to Wood, G. H., EPA. May 9, 1979. Trip report for visit to Maryland and Pennsylvania to identify roads surfaced with serpentinite.

18. Memo from Mumma, C. E., Midwest Research Institute, to Wood, G. H., EPA. June 29, 1979. Trip report for visit to San Francisco and Sonora, California, to identify roads surfaced with serpentinite.

19. Memo from Warner, R. A., Midwest Research Institute, to Wood, G. H., EPA. July 9, 1979. Trip report for visit to Oregon and California to assess the use of crushed stone containing chrysotile.

20. Memo from Serra, R. K., Midwest Research Institute, to Wilson, R., EPA. April 29, 1980. Trip report for visit to Albemarle County, Virginia, to collect samples of crushed serpentinite used on county roads.

21. Telecon: Serra, R. K., Midwest Research Institute, with Mr. Sprinkle, Baltimore County, Maryland, Highway Department. August 1, 1979. Status of Baltimore County roads surfaced with serpentinite.

22. Marklund, D., et.al. Analysis of Crushed Rock Sample Specimens for Measurement of Asbestos Content by Electron Microscopy. Environmental Services Laboratory. University of Minnesota, Duluth, Minnesota. 11 p.

23. Cooper, W. C., et al. Chrysotile Asbestos in a California Recreational Area. Science. 206:685-688. November 1978.

24. Neirinckx, J. Asbestos Status Report. U.S. Forest Service. August 20, 1979. 4 p.

4. EMISSION CONTROL ALTERNATIVES AND ADMINISTRATIVE OPTIONS

4.1 INTRODUCTION

This chapter discusses various control alternatives for reducing or eliminating chrysotile emissions generated by vehicular traffic on unpaved roads surfaced with serpentinite. The administrative policies and regulations that could be modified to prevent future surfacing of roads with serpentinite are also discussed. Because economic and meteorological conditions vary widely throughout the United States, EPA believes that local, State, and Federal agencies should perform their own analyses to determine the most cost effective dust control strategy for reducing local asbestos emissions.

4.2 EMISSION CONTROL ALTERNATIVES

Studies have shown that elevated airborne asbestos concentrations occur near unpaved, untreated roads surfaced with serpentinite when traffic creates dusty conditions. Measures which reduce particulate emissions (dust) from these roads will also reduce asbestos emissions. The factors that influence dust emissions resulting from vehicular use of unpaved roads include: miles of unpaved roads; vehicle speed, weight, and number of wheels; average daily traffic on each road; silt content of the road surface; and the number of dry days per year. Particulate emissions can be reduced by (1) reducing the vehicular variables through the use of traffic controls and (2) reducing the silt variable by applying dust suppressants, by adding gravel, or by paving.

Various emission control alternatives are compared in Table 4-1 and are discussed in detail in the remainder of this chapter. Secondary benefits of the various alternatives, such as reduced maintenance costs, are not considered in the cost figures. Two other factors, road safety and the cost of money, also are not included in the calculations. The

TABLE 4-1. A COMPARISON OF CONTROL ALTERNATIVES FOR REDUCING CHRYSOTILE EMISSIONS FROM UNPAVED ROADS[1-18]

	Control option	Initial cost[a] $1,000/mi	Annual maintenance cost $1,000/mi	Ten-year total cost $1,000/mi	Ten-year total cost $1,000/mi (midrange)	Annual efficiency percent chrysotile controlled[b]	Frequency of application[c]	Adverse environmental impacts	Ease of driving
1.	Stone replacement	32	0.6-2.5	37-55	46	100	1 time	None	No change
2.	Single-coat chip seal	5-8	0.8	21-30	26	90-99.9	3 times/ 10 yr	None	Excellent
3.	Triple-coat chip seal	20-37	0.2	22-39	31	90-99.9	1 time/ 10 yr	None	Excellent
4.	Petroleum products	4-11	4-11	40-110	75	60-85	2 times/yr	None	Good
5.	Lignosulfonate[d]	3.6-8.5	3.6-8.5	36-85	61	60-80	1 time/yr	None	Good
6.	Calcium chloride	3-5	3-5	30-50	40	60-80	3 times/yr	Yes	Good
7.	Water and wetting agents	27-42	27-42	270-420	345	40-60	3 times/wk	None	Fair
8.	Speed control 30-10 mph	0	0	96-304[e]	199	66	--	None	No change
9.	Speed control 30-20 mph	0	0	24-76[e]	50	33	--	None	No change
10.	Stone replenishment	21	0.6-2.5	26-44	35	f	1 time/yr	None	No change

[a] Costs include labor and surface preparation. All cost figures are in 1979 dollars.
[b] Assumed to be proportional to efficiency in controlling dust emissions.
[c] Applications necessary to maintain annual efficiency rating.
[d] The cost of lignosulfonates may be significantly reduced if a local supply can be secured at nominal cost.
[e] Estimated social cost of time "lost" by traveling slower. An average daily traffic volume of 100 vehicles was assumed. The range represents the value of lost time for individual ($4 per car-hour) and commercial drivers ($12.50 per vehicle-hour).
[f] Not known.

wide ranges in the cost estimates and control efficiencies for some of the control alternatives reflect the influence of regional variation.

4.2.1 Stone Replenishment

Chrysotile emissions from roads surfaced with serpentinite can be reduced by the addition of several inches of crushed stone that does not contain chrysotile. This action would reduce the concentration of chrysotile in the surface material and, therefore, also reduce the rate at which chrysotile fibers are released to the atmosphere. No adverse environmental impacts are associated with stone replenishment.

The cost of adding a 10-cm (4-in.) crushed stone surface to a 6.4-meter-wide (20-ft-wide) secondary road is approximately $13,000/km ($21,000/mi). This figure assumes that 2,140 Mg/km (3,100 tons/mi) of stone would be needed at a cost of $7.20/Mg ($7/ton) for the stone "in place." One-half the cost is for labor, equipment, and transportation.[1]

4.2.2 Stone Replacement

In some areas chrysotile emissions could be eliminated by removing the chrysotile-containing stone from the surface of the road. No adverse environmental impacts are foreseen from implementation of this alternative provided that worker exposure to dust is minimized during the removal process and the removed stone is not reused where it is subjected to abrasion likely to generate dust.

The Harford County (Maryland) Road Department estimates the cost of stone removal in their area to be over $6,250/km ($10,000/road-mi). This figure does not include the cost of replacing the stone. Total cost of resurfacing a mile of road with crushed stone is estimated to be $32,000.[2]

4.2.3 Paving

Paving includes the use of a variety of surfacing materials. Three general types of pavement are bituminous concrete, concrete, and chip seals.

4.2.3.1 Bituminous Concrete and Concrete Surfaces. Roads constructed with these two materials are designed to support heavy traffic. Because of their high initial cost, these pavements are not generally used to surface secondary roads. Bituminous concrete is a hot mixture of asphalt and a well-graded aggregate, and concrete is a composite material of cement, water, and aggregate. Concrete requires less maintenance and is more durable than bituminous surfaces.

4.2.3.2 Chip Seal Surfaces. Chip seal surfaces, also called macadam, consist of one to three layers of aggregate and asphalt. The asphalt is sprayed over each aggregate layer, top-dressed with a covering of smaller stones, and compacted. Finished chip seals usually are from 1 to 4 cm thick. Two types of asphalt are used for chip seal surfaces: emulsified asphalt and cutback asphalt. Emulsified asphalts contain an emulsifying agent, water, and asphalt. Asphalt emulsions are cured by the evaporation of water from the mixtures. Cutback asphalts are formed by adding various amounts of volatile solvents (up to 30 percent kerosene or naphtha) to the bituminous mixture. The asphalt hardens as the solvents evaporate into the atmosphere.

No adverse environmental impacts are foreseen if emulsified asphalts are used in chip seal construction; however, care should be taken when handling emulsifying agents since most are corrosive to the skin. Many of the asphalt emulsions (cationic emulsions) can be applied to wet or dry surfaces and are unlikely to be washed away by sudden rain showers. Other emulsions (anionic emulsions) can more readily be flushed from the roadways by rain into receiving streams. Emulsified products are generally stable, nonvolatile, and relatively nontoxic. The use of cutback asphalts should be avoided because of air pollution considerations and because they are highly flammable.

Chip-sealing any unpaved road binds the surface material and prevents loose material below the surface from being emitted to the atmosphere. Annual dust control efficiencies of paved surfaces have been estimated by researchers to range from 90 to 99.9 percent.[3] A typical triple-seal chip surface 3.75 cm (1.5 in.) thick can be expected to serve up to 10 years before additional surface treatment is required. Single chip seal coats generally require a second chip seal after 1 year and another seal in approximately 5 years.[4]

4.2.3.3 Costs. Bituminous concrete costs from \$34,000 to \$63,000/km (\$55,000 to \$100,000/mi) for a 7.6-cm (3-in.) surface over a two-lane area. Costs for the same area for a concrete surface can be up to three times as high. The cost of a single chip seal coat over a crushed stone road base ranges from \$3,125 to \$5,000/km (\$5,000 to \$8,000/mi). A triple coat treatment of three layers of aggregate and asphalt costs from \$12,500 to \$21,900/km (\$20,000 to \$35,000/mi).

4.2.4 Traffic Controls

Dust emissions generated by vehicles are proportional to vehicle speed.[5] Thus, lowering the speed limit on an unpaved road will reduce the dust emissions generated by traffic on the road. To a lesser degree, the number of wheels and weight of a vehicle also influence the amount of dust generated. No adverse environmental impacts are foreseen in implementing traffic controls.

4.2.4.1 Effectiveness. Theoretically, a 66 percent reduction in the level of dust could be achieved solely by reducing speed limits from 30 mph to 10 mph. Preventing one 10-wheel truck (weighing 20 tons) from traveling on an unpaved road effectively reduces the emissions that would be generated by eight 4-wheel (2-ton) vehicles traveling at the same speed. The actual effectiveness of traffic controls may be less than theoretical estimates because traffic controls depend largely on voluntary compliance by drivers and the degree to which regulations are enforced.

4.2.4.2 Costs. The monetary costs of establishing traffic controls are negligible, but the social costs are significant. One social cost would be the "cost" of increased travel time related to lower speed limits. One researcher estimates personal travel time to cost between \$1.68 and \$6.57 per hour traveled.[6] The Interstate Commerce Commission (ICC) estimated the value of time losses for commercial vehicle drivers to be from \$7.66 to \$17.39 per hour traveled (1977 figures).[7] Using ICC's value, a truck traveling 60 miles a day would require one extra hour in transit if speed limits were reduced from 30 mph to 20 mph. The cost of additional travel time in this case would be from \$0.13 to \$0.29 per mile traveled.

4.2.5 Dust Suppressants

Several types of dust suppressants are commercially available. The four major types used on unpaved roads are water/wetting agents, calcium chloride ($CaCl_2$), lignosulfonate, and petroleum products. A partial list of dust suppressant manufacturers is shown in Table 4-2. Detailed treatment instructions are available from manufacturers and should be consulted to ensure proper application. The efficiency of any dust suppressant depends upon (1) soil properties of the road, (2) construction of the road, (3) method and frequency of suppressant application, (4) type and volume of vehicular traffic, and (5) local weather conditions.

4.2.5.1 Watering and Wetting Agents. Watering has been used successfully on unpaved roads only for short-term dust suppression in circumstances where the roads are confined to a small area, such as access roads to mines, quarries, or construction projects. Wetting agents are often mixed with water to extend the effect of roadway watering. These agents reduce the surface tension of water and promote penetration to the subsurface. Moisture that evaporates from the soil surface is replaced by subsurface moisture through capillary action. No adverse environmental impacts have been reported concerning the use of wetting agents.

4.2.5.1.1 Application. It requires approximately 1,100 gallons of water to spray one mile of secondary road at a rate of 0.1 gallon of water per square yard. The dilution ratio of water to wetting agent varies from 1,000 to 10,000 gallons of water per gallon of wetting agent depending upon soil conditions and manufacturer's recommendations. Compacted soils require less water than looser surfaces.

4.2.5.1.2 Effectiveness/durability. The frequency of water application depends primarily upon local weather conditions. Suppressing dust with water alone as a permanent control measure would require an application every day that is dry and has a temperature above 32°F. No test data have been reported assessing the relative control efficiencies of wetting agents. One manufacturer claims that wetting agents can extend the usefulness of road watering by 33 percent.[8]

4.2.5.1.3 Costs. As a permanent control measure, road watering is estimated to cost from $25,600 to $39,000/km per year ($41,000 to $63,000/mi per year).[5] Regional variations in water prices, not considered here, would be expected to increase the geographical variation in these annual costs. If wetting agents are used, the cost of wetting roads could be reduced to $17,000 to $26,000/km per year ($27,000 to $42,000/mi per year).

TABLE 4-2. DUST SUPPRESSANT MANUFACTURERS[8] [9]

	Company name[a] and address	Product trade name[a]	Chemical type of product
1.	ALCO Chemical Corporation Philadelphia, Penn.	Soil Gard	Elastometric polymer emulsion
2.	Allied Chemical Morristown, N.J.	Calcium chloride	Calcium chloride
3.	American Can Company Greenwich, Conn.	Norlig	Calcium Lignosulfonate
4.	American Corporation	Curasol	Polymer emulsion
5.	American Cynamid Company Wayne, N.J.	Aerospray R	Water synthetic resin
6.	American Hoeschst Corporation Someville, N.J.	DCA-70 Curasol	Organic polymer Polymer elastics dispersion
7.	Arthur C. Trask Company	Trastan	Lignosulfonate
8.	Gordon Chemical Company Leominister, Mass.	Polyco 2607 Polyco 2440	Synthetic copolymer Copolymer
9.	Celtite, Inc. Cleveland, Ohio	Polybind DLR	Polymer
10.	Crown Zellerbach Company East Hanover, N.J.	Orzan	Lignosulfonate
11.	Dowell Division, Dowell Chemical Company Tulsa, Okla.	Latex M145 Latex M166	Latex binder
12.	Firestone Tire and Rubber Company Akron, Ohio	FRS-275	Latex in oil or water
13.	Fire Water Company Los Altos, Calif.	Crust 500 SC-100	Polyvinyl acetate organic polymer

TABLE 4-2. DUST SUPPRESSANT MANUFACTURERS[8] [9] (concluded)

	Company name[a] and address	Product trade name[a]	Chemical type of product
14.	Great Salt Lake Minerals and Chemical Corp. Little Mountain, Utah	Dustgard	Clacium chloride
15.	Henly and Company, Inc. New York, N.Y.	Huls-801	Liquid plastic
16.	Hercules, Inc. San Francisco, Calif.	SDX-1	Resin emulsion
17.	E. F. Houghton Company Philadelphia, Penn.	Rozosal	Organic polymer
18.	Johnson March Corporation	MR	Wetting agent
19.	Phillips Petroleum Company Bartletsville, Okla.	Arcatice	Liquid asphalt emulsion
		Dust pallative	Residual oil
20.	Phillips Petroleum Company Great Falls, Mont.	Various oils	Residual oil
		Petroset	Rubber emulsion
21.	Protex Industries, Inc. Denver, Colo.	Soiltex	Lignosulfonate
22.	Rohm and Haas Company Philadelphia, Penn.	Polyacrylic acid	Polyacrylic acid
23.	Sherex Chemicals Chicago, Ill.	Arosurf AA	Cationic asphalt emulsion
24.	Standard Oil Company	Dust control	Petroleum resin
25.	3-M Company St. Paul, Minn.	Lanolock XA-2440	Adhesive binder
26.	Witco Chemical Bakersfield, Calif.	Coherex	Water emulsion of petroleum resins
		Semi-Pave	Asphalt emulsion

---

[a] Material names and manufacturers are included for the benefit of the reader and infer no endorsement or preferential treatment by EPA.

TABLE 4-2. DUST SUPPRESSANT MANUFACTURERS[8, 9]
(concluded)

	Company name[a] and address	Product trade name[a]	Chemical type of product
14.	Great Salt Lake Minerals and Chemical Corp. Little Mountain, Utah	Dustgard	Clacium chloride
15.	Henly and Company, Inc. New York, N.Y.	Huls-801	Liquid plastic
16.	Hercules, Inc. San Francisco, Calif.	SDX-1	Resin emulsion
17.	E. F. Houghton Company Philadelphia, Penn.	Rozosal	Organic polymer
18.	Johnson March Corporation	MR	Wetting agent
19.	Phillips Petroleum Company Bartletsville, Okla.	Arcatice Dust pallative	Liquid asphalt emulsion Residual oil
20.	Phillips Petroleum Company Great Falls, Mont.	Various oils Petroset	Residual oil Rubber emulsion
21.	Protex Industries, Inc. Denver, Colo.	Soiltex	Lignosulfonate
22.	Rohm and Haas Company Philadelphia, Penn.	Polyacrylic acid	Polyacrylic acid
23.	Sherex Chemicals Chicago, Ill.	Arosurf AA	Cationic asphalt emulsion
24.	Standard Oil Company	Dust control	Petroleum resin
25.	3-M Company St. Paul, Minn.	Lanolock XA-2440	Adhesive binder
26.	Witco Chemical Bakersfield, Calif.	Coherex Semi-Pave	Water emulsion of petroleum resins Asphalt emulsion

[a] Material names and manufacturers are included for the benefit of the reader and infer no endorsement or preferential treatment by EPA.

4.2.5.2 Calcium Chloride ($CaCl_2$) Treatment. Calcium chloride has been used by many county road departments for several decades to mitigate summer road dust and as a road deicer in winter. An EPA report in 1971 estimated that approximately 330,000 Mg (300,000 tons) of $CaCl_2$ are spread annually on United States highways.[10] Calcium chloride is a deliquescent material and is able to absorb and retain moisture from the atmosphere at relative humidities as low as 29 percent.[3]

4.2.5.2.1 Application. Road surface conditions and traffic volume dictate the amount, timing, and frequency of calcium chloride application. Calcium chloride, in either the liquid or flake form, is usually first applied in the spring and is followed by a second application 3 to 6 weeks later. According to one vendor, several applications are required to build up a hard pack surface that will substantially reduce dusting for prolonged periods. For roads with a traffic volume of 200 to 300 vehicles per day, three applications within a 15-day period may be required.[11]

Typically, 0.27 Mg (600 lb) of the flake form or 3,785 ℓ (1,000 gal) of a liquid $CaCl_2$ solution are applied per lane-mile. The dry flake $CaCl_2$ is distributed onto the surface by means of an automatic spreader. Liquid $CaCl_2$ is best applied by a truck equipped with a stainless steel tank and a spray bar controlled by a pump that meters out the solution at the desired constant spray rate.

4.2.5.2.2 Effectiveness/durability. A recent study by the Nebraska Health Department found that a single application of a 38 percent $CaCl_2$ solution, applied at a rate of 0.9 ℓ/m^2 (0.2 gal/yd^2) to an unpaved road with a traffic volume of 200 to 300 vehicles per day, significantly reduced the total inhalable particulates* for a period of 2 to 3 weeks.[11] The reduction of inhalable particles was approximately 40 to 50 percent after 19 days. Over a 3.5-month period with liquid $CaCl_2$ applied at 3- to 4-week intervals, total suspended particulate (TSP) levels were reduced by 81 percent on an unpaved road that carried 200 to 300 vehicles per day. Similar applications on a road that carried 700 vehicles per day produced a 66 percent reduction in TSP.[11]

---

*Particles smaller than 10 μm in diameter.

No quantitative test data for the flake form are known; however, the Virginia Highway Department has reportedly controlled road dust over the past several years by applying flake $CaCl_2$ two to three times per summer.[12]

4.2.5.2.3 Costs. The cost of treating a mile of road (20 ft wide) with $CaCl_2$ is about $375/km ($600/mi) per application, excluding labor. Annual costs per mile would depend upon the number of applications necessary in a particular region. The annual cost for calcium chloride treatment has been estimated to range from $3,000 to $5,000 per year. One county road department, however, has calculated that the actual net cost of treating a mile of unpaved road to be less than $100 when reduced maintenance costs and aggregate savings are considered.[13]

4.2.5.2.4 Environmental compatibility. Studies have shown that salts initially penetrate a road to a depth of several inches and then, with time, rise to the surface by capillary action. Surface salts may be washed off the road by rainfall. Certain species of trees and shrubs located adjacent to the road can be adversely affected. Susceptible species include white pine, hemlock, sugar maple, red maple, and most ornamentals.[14] The chronic and acute toxicity of salt in most sensitive plants is well documented, but very little is known about the subtle effects of low levels of salt contamination to "resistant" species after repeated applications over a long periods of time. Salt disrupts the osmotic balance within plant cells and interferes with normal photosynthesis and respiratory processes. Small amounts of salt absorbed through the roots will lead to premature coloration of leaves and early leaf fall the next year. With an acute dose, the plant dies, and the salts contained therein are recycled to the roadside environment.

The aquatic environment can also be adversely affected by direct runoff of dissolved salt to waterways. In concentrations greater than one percent, all fresh water species of bacteria, algae, invertebrates, fish, and higher plants are placed in immediate jeopardy.[14] Small concentrations of salt appear to act selectively on organisms, favoring the salt-tolerant species. Salt-induced stratification in small bodies of fresh water can delay or prevent seasonal mixing and thus contribute to the deoxygenation of the lower depths. Studies indicate that highway salts can also accelerate contamination of ponds and lakes by mercury and other toxic heavy metals by interfering with the ability of bottom sediments to bind these toxic substances.[14]

4.2.5.3 Lignosulfonate. Lignosulfonate is a water soluble liquid chemical byproduct of the wood pulping industry that can be applied to road surfaces for dust suppression. The solution drys, and the lignin fraction serves as a glue that binds fine dust particles. The sulphite liquor appears to stabilize the road surface by decreasing soil permeability.[15]

The soils best suited for lignosulfonate treatment are those where 70 to 100 percent of the particles pass through a 3/4-in. sieve and 50 to 20 percent are silt (i.e., particles that will pass through a 200-mesh sieve).[16]

4.2.5.3.1 Application. Best results are obtained when the road is initially scarified to a depth of 3 in. Usually, a 10 to 25 percent lignosulfonate solution (in water) is applied at a rate of 4.5 to 9.0 ℓ/m^2 (1 to 2 gal/yd^2) and mechanically mixed with the soil. Common practice in road stabilization is to apply 0.5 to 1.0 percent of lignin sulfonate solids by weight in the soil. Following mixing, the road should be formed into a modified A-crown with a uniform side slope of about 1/2 in./ft from the centerline. Proper crown construction is imperative because lignosulfonate-treated roads require rapid surface drainage. As a final step, the road surface is top-dressed with lignosulfonate and compacted with a roller.[16]

4.2.5.3.2 Effectiveness. Satisfactory dust control efficiencies using lignosulfonate have been reported. A mixture of lignosulfonate and a silicate base compound were applied to a test road in Arizona. Five months after application, 80 percent dust control was achieved for both spray-on and mixed-in applications. A lesser degree of dust control was achieved at 14 months.[17]

Lignosulfonates have also been tested on mine access roads where dust problems are often caused by heavy vehicles. It is estimated that 70 percent dust control efficiency over a period of a year can be achieved with an annual application of 2.4 gal of 12 percent lignosulfonate solution per square yard of roadway.[8]

4.2.5.3.3 Costs. Lignosulfonate treatment has been estimated to cost from \$2,250 to \$5,300/km (\$3,600 to 8,500/mi).[4 8 16] The costs may be much lower if a local supply of lignosulfonate can be found. Lee County, Iowa, for example, has solved a disposal problem for a local pulp manufacturer by hauling away the plant's waste lignosulfonate at no cost for the material. The county's average annual cost for lignosulfonate treatment is about \$250/km (\$400/mi). Costs include aggregate, application, and hauling.[15]

4.2.5.3.4 Environmental compatibility. The toxic effects of lignosulfonates are minimal. Calculations show that a 2 percent lignosulfonate stabilized roadway subjected to a 1-in. rainstorm (while assuming unrealistically that 100 percent of the lignosulfonate goes into solution) produces a runoff stream of about 1 percent lignosulfonate by solid weight.[17] This value is well below the maximum 4 percent concentration of lignosulfonate solids allowable for animal ingestion as permitted by the Food and Drug Administration (CFR 121.234). No studies have been found that have investigated the effect of lignosulfonates on aquatic systems.

4.2.5.4 Petroleum Products and Other Chemical Dust Suppressants. Over 20 petroleum-based dust suppressants are commercially available. These chemicals are generally classified by their active ingredient (emulsion, resin, latex, or polymer) and are effective dust suppressants because they agglomerate soil particles and do not mix with water.

4.2.5.4.1 Application. Petroleum-based dust suppressants can be either be sprayed on or mixed into the road material. Typical rates for spray-on application range from 1.0 to 9.0 ℓ/m^2 (0.25 to 2.0 gal/yd^2). Mixed-in applications require about twice as much material.[8 17]

4.2.5.4.2 Effectiveness/durability. Very good results were reported in the Arizona Field Tests (1976) using an emulsion and a petroleum resin to control road dust.[17] These chemicals were applied to an unpaved road that had granitic soil, an average daily traffic of 140 vehicles, and a surface soil silt content of 28 percent. Four different dust suppressants were tested with both spray-on and mixed-in types of application. The percentage of dust controlled by each suppressant 5 months and 14 months following application is shown in Tables 4-3 and 4-4.

TABLE 4-3. PERFORMANCE RATINGS AND ROAD CONDITIONS FOR SELECTED ROAD STABILIZERS MIXED INTO SOIL[17]

Chemicals[a]	Cost of chemical and its applications[b] $/mi	After 5 months		After 14 months		Cost effectiveness[c] $/ton of dust emissions prevented
		Percent[d] control	Description of road condition	Percent control	Description of road after several bladings 9/29/75	
Redicote E52 asphalt emission: A cationic asphalt emulsion (7.45% in water) applied at 2.4 gal/yd².	10,810	94.7	Black, very hard, asphalt-like surface; little wear; smooth; no loose material; no dust behind traffic.	84.4	Black, very hard, asphalt-like surface; little wear; good riding quality; some loose coarse material; very little dust behind traffic.	17.0
Dust Bond 100 + F-125: A mixture of lignin sulfate and other chemicals plus Formula 125. Applied at 1 gal/yd².	8,440	86.6	Brown, hard surface; smooth; little wear; some loose material; very light dust behind traffic.	44.7	Brown; few hard spots; numerous ruts and potholes; heavy dust concentration behind traffic.	18.1
Dust control oil mixture of petroleum resin and light hydrocarbon solvent. Applied at 0.5 gal/yd².	4,370	80.5	Black, hard at spots; few ruts and potholes; loose coarse material; moderate dust behind traffic.	11.5	Dark brown; hard at few spots; numerous ruts and potholes; heavy dust cloud behind traffic.	13.4
Water	600	0	Natural color; rutted; several potholes; substantial loose material; heavy dust behind traffic.	0	Natural color; rutted; numerous potholes; substantial loose material heavy dust cloud behind traffic.	---

[a] Mixing of the chemical stabilizer into the road bed is accomplished as follows: (1) the surface is first ripped to a depth of 3 inches; (2) the surface is sprayed with water; (3) the chemical is sprayed on the surface; (4) the chemical is mixed into the soil surface with a series of successive bladings; and (5) the road surface is compacted by rolling.

[b] Based on state cost figures for chemical stabilizers, adjusted 15 percent upward to reflect current (1976) costs and adjusted andther 10 percent to include cost of surface preparation and chemical application. Correction to current costs are based on communication with a principal supplier. Costs include shipping expenses from supplier to Phoenix.

[c] Cost effectiveness is based on the ratio of the cost and the average emissions reduction attained for the period indicated. This reduction is estimated by applying the control figures above to the uncontrolled dust emissions corresponding to an unpaved road with ADT of 140, soil silt content 28 percent, and average vehicle speed of 35 mph. Roadway dust emissions without control are 712 tons for the 14-month period.

[d] Control effectiveness is based on dustfall measurements conducted at various distances from road.

TABLE 4-4. PERFORMANCE RATING AND ROAD CONDITIONS FOR SELECTED ROAD DUST SUPPRESSANTS, SPRAY-ON APPLICATION[17]

Chemicals	Cost of chemical and its application[a] $/mi	After 5 months		After 14 months and several bladings		Cost effectiveness[b] $/ton of dust emissions prevented
		Percent control[c]	Description of road condition	Percent control	Description of road after several bladings 9/29/75	
Dust control oil: Mixture of petroleum resin and light hydrocarbon solvent. Applied at 0.6 gal/yd².	5,200	95.2	Black, very hard surface; some potholes near shoulders; minimal loose material; extremely light dust behind traffic.	54.3	Dark brown, hard surface; scattered scattered potholes; moderate loose loose material but from outside the side the road; light dust behind traffic.	9.3
Curasol AE: A polymer dispersion diluted in water by 6 to 1. Applied using 4 passes at 0.25 gal/yd² each.	8,130	86.9	Dark brown, medium hard surface; rutted with few potholes; loose coarse particles on surface; moderate dust behind traffic.	9.4	Brown; several ruts and potholes; large amount of loose particles; very heavy dust traffic.	23.8
Aerospray 70: A polyvinyl acetate resin diluted 6 to 1 with water. Applied using 4 passes at 0.25 gal/yd² each.	8,000	82.6	Brown, medium hard surface; medium wear and ruts; few potholes; loose coarse particles on surface; moderate dust behind traffic.	44.3	Lt. brown; several ruts and potholes; large amount of loose particles; heavy dust behind traffic.	18.0
Dust Bond 100 + F-125: Mixture of lignin sulfate and other chemicals. Applied nondiluted in first pass at 1 gal/yd² then at 1-to-1 dilution plus 2.5% Formula 125 on next pass. Surface compacted intermittently for several hours after application.	8,420	88.0	Brown, medium hard surface; moderate wear; few potholes; smooth surface; slippery when wet; moderate dust behind traffic.	17.6	Lt. brown; few patches of treated surface; several ruts; large amount of loose particles; heavy dust behind traffic.	22.4
Foramine 99-194: A urea-formaldehyde resin in water solution. Diluted 1.6 to 1 by water application at 1 gal/yd².	10,300	46.6	Natural color; worn and rutted surface; large amount of loose particles; poor riding quality; heavy dust behind traffic.	8.9	Natural color; similar to untreated (water) section.	52.2
Water	400	0	Natural color; soft when wet; worn and rutted surface; large amount of loose particles; heavy dust cloud behind traffic.	0	Natural color; worn; numerous ruts ruts and potholes; large amount of loose particles; heavy dust cloud behind traffic.	---

[a] Based on 1975 state cost figures for chemical stabilizers, adjusted 15 percent upward to reflect current (1976) costs and another 10 percent to include cost of surface preparation and applications. Correction for adjustment to current costs is based on personal communication with a principal supplier. Costs include shipping expenses for supplier to Phoenix.

[b] Cost effectiveness is based on the ratio of the cost and the average emissions reduction attained for the period indicated. This reduction is estimated by applying the control figures above to the uncontrolled dust emissions corresponding to an unpaved road with ADT of 140, soil silt content of 28%, and average vehicle speed of 35 mph. The uncontrolled emissions are 254 tons per mile of road for the 5-month period, and 712 for the 14-month period.

[c] Control effectiveness is based on dustfall measurements conducted at various distances from road.

4.2.5.4.3 Costs. An obvious disadvantage in using petroleum-based dust suppressants is cost. Cost figures listed in Tables 4-3 and 4-4 range from $3,125 to $6,250/km per year ($5,000 to 10,000/mi per year).

4.2.5.4.4. Environmental compatibility. Certain characteristics of emulsified asphalt products indicate that these dust suppressants are environmentally compatible. In general, they are noncorrosive, insoluble in water, nonevaporative, relatively nontoxic, and do not adversely affect plant life.

The petroleum-based resins containing hydrocarbon solvents can cause air pollution when the solvents evaporate. No data have been reported concerning the environmental compatibility of latex and polymeric products.

4.2.6 Control Techniques Summary

The cost effectiveness of applying gravel, a triple-coat chip seal, asphalt concrete, and dust control oil to reduce dust emissions from an unpaved dirt road with an average daily traffic of 100 vehicles was determined by the Maricopa County (Arizona) Highway Department in 1976. The study found that the chip seal surface was the most cost effective alternative ($10.80 per ton of dust controlled) followed by a gravel surface ($11 per ton of dust controlled), the oiled surface ($19.50 per ton of dust controlled), and, lastly, the 3-in. asphalt concrete surface ($19.60 per ton of dust controlled). The annual dust control efficiency was 100 percent for both paved surfaces (neglecting dust entrainment off the pavement), while the annual dust control efficiencies of the gravel and oiled surfaces were 50 and 75 percent, respectively.[17]

A similar study conducted by the Seattle Public Works Department also showed that the most cost effective method of controlling road dust is a chip seal if a road's average daily traffic is over 100 vehicles. Additional benefits from the chip seal surface that were not included in determining its cost effectiveness were: reduced road maintenance costs, reduced sewer costs, higher property values, lower vehicle operating costs, and lower health costs.[18]

4.3 ADMINISTRATIVE OPTIONS

The administrative options in this section discuss how existing State and Federal policies and regulations can be modified to eliminate chrysotile emissions from unpaved roads and to prevent the surfacing of unpaved roads with stone containing chrysotile in the future.

4.3.1 Modify Crushed Stone Procurement Practices

A State or Federal agency can discontinue the purchase of crushed serpentinite for surfacing unpaved public roads. Specifications of crushed stone for road use can require quarry owners to prove that the stone contains no chrysotile. New sources of crushed stone may have to be developed in some areas.

4.3.2 Review Criteria for Road Paving Priorities

Unpaved serpentinite roads can be given high priority for paving. Selective paving of the dusty, unpaved roads containing chrysotile can significantly reduce local chrysotile emissions. Particular attention should be given to residential areas.

4.3.3 Implement Traffic Controls

Lower speed limits can significantly reduce the amount of dust generated by moving vehicles on unpaved roads if such controls are enforced. The same is true for limiting the size and weight of commercial vehicles.

4.3.4 Review State Mining Permit Requirements

Petrographic analyses of rock samples may be required of new quarries planning to operate in areas where serpentinite is likely to occur. A State may wish to regulate the end uses of serpentinite containing chrysotile by adding end-use restrictions in the operating permit. Existing quarries can be brought into compliance with the new requirements when permits are renewed.

4.3.5 Revise Existing Fugitive Dust Regulations

Most States have general regulations requiring that reasonable precautions be taken to prevent dust from becoming airborne. In the case of fugitive dust generated from unpaved roads surfaced with serpentinite, a maintenance standard or a no-visible emission standard may be vigorously enforced. Standards may require the implementation of dust control programs, air monitoring, and/or traffic controls.

4.4 REFERENCES FOR CHAPTER 4

1. Telecon. Bradshaw, D., North Carolina Department of Transportation, with Serra, R., Midwest Research Institute. February 4, 1980. Cost of constructing crushed stone roads.

2. Telecon. Rutheford, J., Harford County, Maryland, Road Department, with Serra, R., Midwest Research Institute. January 11, 1980. Cost of replacing crushed stone on Harford County roads.

3. Setting Priorities for Control of Fugitive Particulate Emissions From Open Sources. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-600/7-79-186. August 1979. 128 p.

4. Guideline for Development of Control Strategies in Areas With Fugitive Dust Problems. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-450/2-77-029. October 1977. 158 p.

5. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-450/3-74-037. June 1974.

6. Winfrey, R. Economic Analysis for Highways. Scranton, Pennsylvania. International Textbook Co. 1969.

7. Statistical Abstract of the United States: 1977 (98th ed.). U.S. Bureau of the Census. Washington, D.C. 1977.

8. Bohn, R., et al. Dust Control for Haul Roads. U.S. Bureau of Mines. February 1981. 146 p.

9. Jutze, G. and K. Axetell. Investigations of Fugitive Dust. Volume I: Sources, Emissions, and Control. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-450/3-74-036a. June 1974. 88 p.

10. Field, R. F., H. E. Masters, et al. Water Pollution and Associated Effects From Street Salting. Report 506 Transporration Research Record. Transportation Research Board, National Academy of Sciences. pp. 40-46.

11. Walsh, G. L. Control of Fugitive Dust From Unpaved Roads Using Liquid Calcium Chloride. Final Draft. U.S. Environmental Protection Agency. Research Triangle Park, N.C. 1980. 48 p.

12. How Virginia Controls Road Dust Annoyance. Rural and Urban Roads. July 1978. pp. 53-54.

13. In Winter Snow or Summer Dust, County Relies on Calcium Chloride. Rural and Urban Roads. November 1978. pp. 56-59.

14. Adams, F. S. Highway Salt: Social and Environmental Concerns. Report No. 425. Highway Research Record. Highway Research Board, National Research Council. pp. 6-8.

15. Fox, P. E. and J. M. Hoover. Ammonium Lignosulfonates as Dust Palliatives and Surface Improvement. Agents for Unpaved Secondary Roads. Part III of Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets. Engineering Research Institute. Iowa State University, Ames, Iowa. July 1973. pp. III-1 through III-104.

16. Harmon, J. P. Use of Lignin Sulfonate for Dust Control on Haulage Roads in Arid Regions. Information Circular 7808. Bureau of Mines. U.S. Department of the Interior. Washington, D.C. October 1957. 11 p.

17. Sultan, H. A. Soil Erosion and Dust Control of Arizona Highways, Part IV. Final Report Field Testing Program. Arizona Transportation and Traffic Institute. Prepared for Arizona Department of Transportation. November 1976. 110 p.

18. Roberts, J. W., H. A. Watters, C. A. Marigold, and A. T. Rossano. Cost and Benefits of Road Dust Control in Seattle's Industrial Valley. Journal of the Air Pollution Control Association. 25:949-952. September 1975.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Asbestos is a proven human carcinogen, and no level of exposure is known below which cancer will not occur. A small number of unpaved secondary and logging roads surfaced with crushed serpentinite have been found in a few areas of the United States. In addition, unpaved roads have been constructed over outcropping of serpentinite in a few areas. Vehicular traffic over these surfaces results in the release of asbestos fibers into the atmosphere thereby exposing a small segment of the general population to low concentrations of a known human carcinogen.

EPA believes that asbestos emissions from unpaved roads and other dusty sources (such as unpaved parking lots) should be reduced to the greatest extent practical. The level of asbestos emissions as well as the most appropriate method to control those emissions varies with location. EPA has concluded that the specific local, State, or Federal agency responsible for road maintenance in these areas is in the best position to assess local conditions and to decide on a proper course of action.

5.2 RECOMMENDATIONS

The Administrator recommends that the responsible levels of government undertake a course of action in the near future to:

1. Perform an exposure assessment in each area where serpentinite may be used to surface unpaved roads. This assessment should:
    a. Locate all unpaved roads that may be surfaced with serpentinite;
    b. Verify the presence of asbestos in the road material or in aggregate storage piles by petrographic microscopy; and
    c. Determine the number of people residing along these unpaved roads and the number of people using such roads.

2. Develop a program to:

a. Eliminate asbestos emissions from unpaved roads surfaced with serpentinite, where practical, by:

(1) Not using existing supplies of crushed serpentinite for surfacing unpaved public roads;

(2) Implementing temporary measures (such as using dust suppressants) to reduce asbestos emissions when dusty conditions are likely to occur; and

(3) Paving as many unpaved serpentinite roads as resources will allow. A schedule for paving should prioritize those roads, or sections of roads, that expose the largest human population to airborne asbestos.

b. Discourage, through administrative and/or regulatory measures, the use of crushed serpentinite for maintaining unpaved public roads;

c. Reduce vehicular activity in areas containing natural outcroppings of serpentinite when dry, dusty conditions are likely to occur;

(1) Limit potential secondary exposures to family members from carry-out of asbestos on clothing/equipment; and

d. Inform those persons who may be exposed to asbestos emissions from unpaved serpentinite roads of the assessment program and inform them of the various diseases associated with the inhalation of asbestos.

APPENDIX A. FEDERAL ASBESTOS REGULATIONS

Appendix A is an overview of current Federal regulations governing the production and use of asbestos and asbestos-containing materials. The major provisions of asbestos regulations promulgated by the Occupational Safety and Health Administration (OSHA), Mine Safety and Health Administration (MSHA), Environmental Protection Agency (EPA), Consumer Product Safety Commission (CPSC), and the Food and Drug Administration (FDA) are contained in Tables A-1 through A-5.

TABLE A-1. OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION ASBESTOS REGULATIONS

Citation	Major provisions
36 FR 10456 (5/29/71)	Air contaminant (gases, vapors, fumes, dust, and mists) regulations. Exposure by inhalation, ingestion, skin absorption, or contact to any material or substance at concentrations above those specified for the given material or substance shall be avoided, or protective equipment shall be provided and used. The concentration specified for asbestos is 12 fibers greater than 5 μm in length per milliliter of air, as determined by the membrane filter method at 430 phase contrast magnification or 2 million particles per cubic foot of air, based on impinger samples counted by light-field techniques.
36 FR 23207 (12/7/71)	Emergency standard for exposure to asbestos dust. The 8-hour TWA (time-weighted average) airborne concentration of asbestos dust to which employees are exposed shall not exceed five fibers greater than 5 μm in length per milliliter of air, as determined by the membrane filter method at 400-450 magnification phase contrast illumination. Concentrations above 5 fibers per milliliter, but not to exceed 10 fibers per milliliter, may be permitted up to a total of 15 minutes in an hour for up to 5 hours in an 8-hour day.
37 FR 11318 (6/7/72)	Standards for exposure to asbestos dust. 1. Standard effective July 7, 1972. The 8-hour TWA airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed five fibers longer than 5 μm per cubic centimeter of air as determined by the membrane filter method at 400-450 magnification with phase contrast illumination. 2. Standard effective July 1, 1976. The 8-hour TWA airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed two fibers longer than 5 μm per cubic centimeter of air.

TABLE A-1. OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION ASBESTOS REGULATIONS (concluded)

Citation	Major provisions
37 FR 11318 (6/7/72) (continued)	3. Ceiling Concentration. No employee shall be exposed at any time to airborne concentrations of asbestos fibers in excess of 10 fibers longer than 5 μm per cubic centimeter of air. Includes methods of compliance, warning signs, monitoring, medical examinations, and recordkeeping.
41 FR 11504 (3/19/76)	• Extends the recordkeeping requirement for exposure monitoring from 3 years to 20 years.

TABLE A-2. MINE SAFETY AND HEALTH ADMINISTRATION ASBESTOS REGULATIONS

Citation	Major provisions
39 FR 24316 (7/1/74)	Health and safety standards for asbestos. The 8-hour TWA airborne concentration of asbestos dust to which employees are exposed shall not exceed five fibers greater than 5 µm in length per milliliter, as determined by the membrane filter method at 400-450 magnification phase contrast illumination. No employee shall be exposed at any time to airborne concentrations of asbestos fibers in excess of 10 fibers longer than 5 µm per milliliter of air, as determined by the membrane filter method over a minimum sampling time of 15 minutes. The term "asbestos" as used herein is limited to the following minerals: chrysotile, amosite, crocidolite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos.
41 FR 10223 (3/10/76)	The 8-hour TWA airborne concentration of asbestos dust to which miners are exposed shall not exceed two fibers per cubic centimeter of air. Exposure to a concentration greater than 2 fibers per cubic centimeter of air, but not to exceed 10 fibers per cubic centimeter of air, may be permitted for a total of 1 hour each 8-hour day. The term asbestos does not include nonfibrous or nonasbestiform minerals. The determination of fiber concentration shall be made by counting all fibers longer than 5 µm in length and with a length-to-width ratio of at least 3:1 in at least 20 randomly selected fields using phase contrast microscopy at 400-450 magnification.

TABLE A-3. ENVIRONMENTAL PROTECTION AGENCY ASBESTOS REGULATIONS

Citation	Major provisions
36 FR 5931 (3/31/71)	Asbestos listed as a potential hazardous air pollutant.
38 FR 8820 (4/6/73)	Promulgation of national emission standards for asbestos. Prohibits the surfacing of all roadways except those on ore deposits with asbestos tailings. Prohibits visible emissions from any part of the asbestos mill, but does not apply to dumps of asbestos tailings or open storage of asbestos ores. Prohibits visible emissions from the nine manufacturing operations which are major sources of asbestos; the standard does not cover fabrication operations. Prohibits visible emissions which contain asbestos from a number of sources and provides the option of using specified air-cleaning methods. Specifies certain work practices which must be followed when demolishing certain buildings or structures which contain friable asbestos material. Limits the asbestos content to no more than 1 percent for spray-on materials used to insulate or fireproof buildings, structures, pipes, and conduits.
39 FR 7526 (2/26/74)	Establishes final effluent limitations guidelines for existing sources and standards of performance and pretreatment standards for new sources within the asbestos-cement pipe, asbestos-cement sheet, asbestos paper (starch binder), asbestos paper (elastometric binder), asbestos millboard, asbestos roofing products, and asbestos floor tile subcategories of the asbestos manufacturing category of point sources.

TABLE A-3. ENVIRONMENTAL PROTECTION AGENCY ASBESTOS REGULATIONS
(continued)

Citation	Major provisions
39 FR 15396 (5/3/74)	Clarification of regulations promulgated 4/6/73 (38 FR 8820). Definitions are presented for "alternative method," "commercial asbestos," "asbestos mill" or "manufacturing" operation, and "demolition."
40 FR 1874 (1/9/75)	Established final effluent limitation and guidelines for several additional subcategories within the asbestos manufacturing category.
40 FR 48292 (10/14/75)	Amendment of the asbestos standard stating that there shall be no visible emissions to the outside air: (1) during the collection, processing, packaging, transporting, or deposition of any asbestos-containing waste material which is generated by manufacturing, fabricating, demolition, renovation, spraying, and milling operations; (2) from operations involving the fabrication of cement building products, friction products, and cement or silicate board if they use commercial asbestos; (3) from the manufacture of shotgun shells and asphalt concrete if they use commercial asbestos. Regulation covers the demolition and renovation of structures which contain any pipe, duct, boiler, tank, reactor, turbine, furnace, or structural member that is insulated or fireproofed with friable asbestos material. Molded insulating materials which are friable and wet-applied insulating materials which are friable after drying, shall contain no commercial asbestos
42 FR 12127 (3/2/77)	Amendment of the asbestos standard. Clarifying the demolition and renovation provisions of the asbestos standard.
42 FR 64572 (12/23/77)	Authorization to identify and regulate any unreasonable risk to health or the environment presented by naturally occurring chemical substances. Asbestos is included as a naturally occurring chemical substance subject to inventory reporting regulations.

TABLE A-3. ENVIRONMENTAL PROTECTION AGENCY ASBESTOS REGULATIONS (concluded)

Citation	Major provisions
43 FR 26372 (6/19/78)	Amendment of the asbestos standard. Extending coverage of the demolition and renovation provisions to all friable asbestos materials and extends coverage of the asbestos spraying provisions to all materials which contain more than 1 percent asbestos. Materials in which the asbestos fibers are encapsulated and which are not friable after drying are exempt from the spraying provisions.

TABLE A-4. CONSUMER PRODUCT SAFETY COMMISSION ASBESTOS REGULATIONS

Citation	Major provisions
42FR 63354 (12/15/77)	Banned consumer patching compounds and artificial emberizing materials (used in fireplaces to simulate live embers and ash) that contain respirable free-form asbestos.

TABLE A-5. FOOD AND DRUG ADMINISTRATION ASBESTOS REGULATIONS

Citation	Major provisions
37 FR 14872 (7/26/72)	Banned asbestos-containing garments, for general use in households, from interstate commerce.
40 FR 11865 (3/14/75)	Established good manufacturing practices to limit asbestiform particles in drugs for parenteral injection. Filters used in manufacturing, processing or packaging of drugs shall not release fibers into such products.
41 FR 3286 (1/22/76)	Revoked regulations that permitted the electrolytic diaphragm process used in salt production because the process does not remove asbestos impurities from salt as well as conventional methods do.

APPENDIX B. SAMPLING AND ANALYSIS OF AIRBORNE CHRYSOTILE ASBESTOS CONCENTRATIONS AT FIVE TEST SITES

B.1 TEST PROGRAM DESCRIPTION

A test program was undertaken by EPA in 1979 to assess airborne chrysotile asbestos concentrations downwind from unpaved roads surfaced with serpentinite, near quarries where serpentinite is mined, and at a recreational area located in a large outcropping of serpentinite.

Upwind and downwind samples were collected near two unpaved roads in Harford County, Maryland to determine the chrysotile concentration of the airborne dust generated by road traffic. The number and speed of automobile passes were monitored during testing. All sampling runs were conducted during a 2-hour time period when the wind direction was predominently perpendicular to the road. Wind speed, wind direction, temperature, relative humidity, and percent cloud cover were recorded at the beginning, the midpoint, and the end of each sampling run. During testing, wind speed and wind direction showed typical periods of calm and gusty conditions about the prevailing wind direction. Sampling was also conducted near an unpaved road in Tuolumne County, California; however, sampling was limited because of fluctuating wind conditions.

Air monitoring was conducted near the boundary of two serpentinite quarries to determine the impact of quarry emissions on ambient air. Sampling was conducted over 4 to 8-hour time periods on several days. Activity within one of the quarries was noted during sampling.

Air monitoring was conducted of a campsite in the Clear Creek Recreational Area, in central California, to determine ambient asbestos concentrations in the area. Meteorological conditions and off-road vehicle activity were noted during the 5-hour sampling period. Airborne particulate samples were also collected at the edge of the unpaved road leading to the campsite and in a vehicle traveling behind another vehicle along the roadway. These sampling runs were each approximately 15 minutes in duration, and the data collected represents peak asbestos concentrations near the roadway when dusty conditions exist.

Both membrane samplers and high-volume samplers were used for collection of airborne particulate samples at all sites except for the recreational area where personnel samplers were used. Membrane samplers collected airborne particulate matter on polycarbonate filters at an air flow rate of 90 liters per minute (ℓ/min). The flow rate through the membrane samplers was calibrated at the beginning of each sampling run with an EPA Audit Orifice which was referenced against a Roots Meter. A quality assurance audit was conducted by an EPA auditor using an independent Roots Meter which had been referenced against National Bureau of Standard reference standards. The pressure drop across the orifice (while calibrating) was measured and compared with the calibration data sheets to determine sampler flow rate at standard conditions. Filters from the membrane samplers were removed after each sampling run and stored for later analysis by electron microscopy (EM) for chrysotile concentration.

The high-volume samplers were used to collect total suspended particulate matter (TSP) on glass fiber filters at a flow rate of approximately 1,100 ℓ/min. These samplers were calibrated at the beginning of the study using a calibrated EPA Audit Orifice. Each sampler was equipped with an electronic flow controller and a Dickson Recorder. Actual flow rates were determined using the recorded data and the calibration curves.

Personnel samplers were calibrated before and after each sampling run using a Hastings Mini-Flo calibrator. Three to five flow measurements were taken for each sampler, averaged, then standardized to determine sample volume per minute.

A sample of the road surface material was collected immediately prior to each sampling run at the road sites. Silt and moisture content were determined for these surface material samples. Each sample was comprised of all the loose material above the road hardpan in a 2.5 m x 12 cm strip across one lane of the road. Six of the roadway samples were later analyzed for asbestos concentration (percent weight) as were one soil sample from the recreation area and a sample of crushed serpentinite produced by one of the two quarries.

B.2 SAMPLE FILTER HANDLING

B.2.1 Sampler Loading

All membrane samplers were equipped with detachable sampler heads. Sampler heads were loaded with a polycarbonate filter and two backup filters before each sampling run. A 102-mm glass fiber filter was placed on the wire mesh support of the sampler head, followed by a 1.0-mm thick Teflon O-ring, and a 102-mm, 5-μm pore size cellulose ester filter (with the uniform pattern side facing down). A 102-mm, 0.4-μm pore size polycarbonate filter was then placed on top of the backup filters with the shiny side facing up. A 2.0-mm thick Teflon O-ring was placed on top of the polycarbonate filter and the filter assembly was secured to the sampler head by three bolts. All loaded membrane samplers were operated simultaneously during each sampling run. Elasped time meters were used to record sampling times.

High volume samplers were loaded with preweighed glass fiber filters before each day's sampling runs.

Personnel filter cassettes (a plastic cyclinder with a capped hole in the top and bottom) were loaded by placing a 37-mm cellulose ester support pad in the bottom of the cassette followed by a 37-mm, 5.0-μm pore size cellulose ester filter and a 37-mm, 0.4-μm pore size polycarbonate filter (shiny side up). At the time of sampling, the cassette was uncapped and connected to the inlet of the personnel sampler with a piece of tygon tubing and a stainless steel male adapter. After a sampling run, the cassette was capped, labeled, and stored in an upright position until carbon coating was applied.

B.2.2 Sampler Unloading

Membrane sampler heads were carried in an upright position to a nearby vehicle that served as a field laboratory for unloading. Forceps were used to transfer the polycarbonate filter from the sampler head to a numbered petri dish. The filter (sample side up) was secured to the bottom of the petri dish by attaching cellophane tape to the unexposed edges of the filter. The petri dishes were then sealed and stored upright for subsequent transportation to the nearest facility, either the University of California at Berkley or the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, where carbon coating was applied.

Glass fiber filters were removed from high-volume air samplers after each day's sampling runs. The filters were covered with a sheet of paper, folded lengthwise, and inserted in a labeled envelope. The envelopes were transported to EPA, Research Triangle Park, where they were reweighed and TSP concentrations were determined.

B.2.3 Carbon Coating of Polycarbonate Filters

Polycarbonate filters were carbon-coated after sampling to prevent rearrangement or loss of asbestos fibers. The coating procedure secures a vapor-deposited layer of carbon onto the filter surface, thus fixing the position of any fibers that are present.

Due to the limited size of the vacuum evaporators, only a portion of each polycarbonate filter was carbon-coated. The 102-mm size filters were carefully sectioned with a scapel and one section was transferred to a smaller petri dish (sample side up). Cellophane tape was used to secure the filter to the bottom of the dish. The 37-mm personnel filters were sliced into two sections while still in the personnel cassette. One section was transferred to a small petri dish and secured with tape. The petri dishes were sealed and sample identification was placed on both the top and bottom of each dish. If a filter section wrinkled or buckled during the cutting or transferring procedure, the filter section was voided and a second section of the filter was prepared.

Three samples, in uncovered petri dish bottoms, were placed on the turntable of the vacuum evaporator. A pure carbon rod was placed in a spring-loaded holder and served as the vaporizing electrode. The rod rested against a flat carbon-faced surface that served as the second electrode to complete the circuit. The bell jar was evacuated until $5\text{x}10^{-5}$ torr was reached, and then the electrode current was quickly increased to 24 ampheres and maintained for 5 seconds. The current vaporized the carbon rod and produced a layer of carbon film over the sampling filters. The bell jar was returned to atmospheric pressure, and the samples were removed and the dish covers replaced.

B.2.4 Filter Shipment

The petri dishes containing the carbon-coated polycarbonate filters were relabeled with a three-digit code number. One hundred and forty-six samples were mailed to Denver Research Institute (DRI), and 70 samples were mailed to Ontario Research Foundation (ORF) for TEM analysis.

Crushed stone samples collected at the various sites were placed in sealed plastic bags, identified by a code number and sent to the University of Minnesota at Duluth (UMD) for TEM analysis.

B.3 SAMPLE ANALYSIS

All samples were prepared and analyzed for chrysotile asbestos following EPA Report 600/2-77-178 with minor modifications to the procedures.[1] Due to unanticipated delays, DRI was able to process only 80 of 143 airborne particulate samples.[2] ORF and UMD processed all samples received. In addition, both ORF and UMD reported chrysotile and amphibole fiber concentrations. (DRI did not have the analytical capability to positively identify amphibole fibers). Amphibole concentrations are not included in this test report but can be found in ORF's and UMD's final reports.[3] [4]

B.3.1 Road Surface Material Samples

UMD determined the mineral fiber content of eight crushed stone samples. The results are presented in Table B-1. The basic procedure used to analyze the samples was the procedure used for analyzing airborne particulate samples. Prior to TEM analysis, a representative portion of each sample was reduced to a powder by grinding and then was ultrasonified in a 0.001 percent aerosol OT* solution for several minutes. The sample volume was adjusted to 1 ℓ and a small measured volume of sample was pipetted and filtered through a 0.1-μm polycarbonate filter. Following filtration, the polycarbonate filter was dried and carbon-coated. TEM analysis was then conducted.

B.3.2 Airborne Particulate Samples

DRI and ORF determined chrysotile fiber concentrations of 150 airborne particulate samples (including three blank filters). The reproducibility and precision of the analytical methodology for determining ambient concentrations of asbestos were evaluated by having a number of split and colocated samples analyzed by both laboratories. Both laboratories reported that "free" asbestiform fibers and "asbestiform fibers associated with other deposits" were present on many of the prepared sample grids. In some cases, the "other deposits" appeared to be composed of mats, sheaves, and/or bundles. Inspection by scanning electron microscopy showed that significant numbers of fibers were present on the sample grids which were not visible in the routine TEM image.

---

*Dioctyl sodium sulfosuccinate.

Chrysotile fibers were positively identified by morphology and by selected area electron diffraction (SAED). Chrysotile fibers have a unique tubular morphology that can be easily distinguished from other types of asbestos. Nearly all the chrysotile fibers observed were shorter than 5.0 µm in length and less than 1.0 µm in diameter. Most of the asbestiform fibers associated with "other deposits" could not be positively identified by SAED because a suitable SAED pattern could not be obtained. In some cases, fibers were too thick to obtain a SAED pattern or too close to other mineral particles to obtain an unambiguous pattern. DRI identified chrysotile fibers associated with such deposits by morphology. ORF observed many asbestiform fibers with slightly altered morphology and classified them as "other asbestiform fibers with tubular morphology resembling chrysotile." ORF strongly suspected that these fibers were chrysotile. ORF did not observe any fibers similar to chrysotile in morphology but which could be shown to be nonasbestos.

The chrysotile fiber concentrations reported in this study are the sum of free chrysotile fiber concentrations, concentrations of chrysotile fibers associated with other deposits, and concentrations of other asbestiform fibers that were strongly suspected of being chrysotile. Only those particles with at least a 3:1 length-to-width ratio were counted as fibers. If one end of a fiber was partially obscured, the length reported was twice the visible length (provided the visible portion had an aspect ratio of 3 or greater).

The methodology used by the participating laboratories allows characterization of respirable fiber concentrations as they occur in the environment; it does not allow for estimation of the potential release of many fibers from a single bundle or sheave. In general, the crystalline deposits observed had mean diameters that ranged in size from submicrometer up to 12.5 µm. In order to assess the potential for release of respirable airborne fibers from these deposits, redispersal of the loosely bound fiber aggregates was recommended by the participating laboratories.

B.3.3 Total Suspended Particulate

TSP was collected by high-volume samplers on preweighed filters at the unpaved road sites whenever three 2-hour sampling runs were conducted on a single day. Each high volume sampler was operated only during the 6 hours of sampling. High volume samplers were not operated on days when fewer than three runs were conducted because TSP loading on the filters would be insufficient for mass determination. TSP mass concentrations were determined by dividing the difference between the final filter weight and the preweight of the filter by the volume of air pulled through the sampler.

B.4 SITE-SPECIFIC TESTS: DESCRIPTION AND RESULTS

Air monitoring for asbestos was conducted between September and December 1979 at the following six sites:

1. Holy Cross Road, Harford County, Maryland
2. McNabb Road, Harford County, Maryland
3. Clear Creek Recreational Area, San Benito County, California
4. Cedar Hills Quarry, Lancaster County, Pennsylvania
5. Woods Creek Quarry, Tuolumne County, California
6. Duffy Road, Tuolumne County, California

B.4.1 Holy Cross Road

Holy Cross Road is an unpaved road in rural Harford County, Maryland. The road is level and surfaced with crushed serpentinite produced by Cedar Hills Quarry. Air sampling was conducted at this site to assess the distribution of airborne asbestos concentrations downwind of a road surfaced with serpentinite. Meteorological data, traffic data, and road surface characteristics were monitored while airborne particulate matter was collected. A diagram of the Holy Cross Road site is shown in Figure B-1.

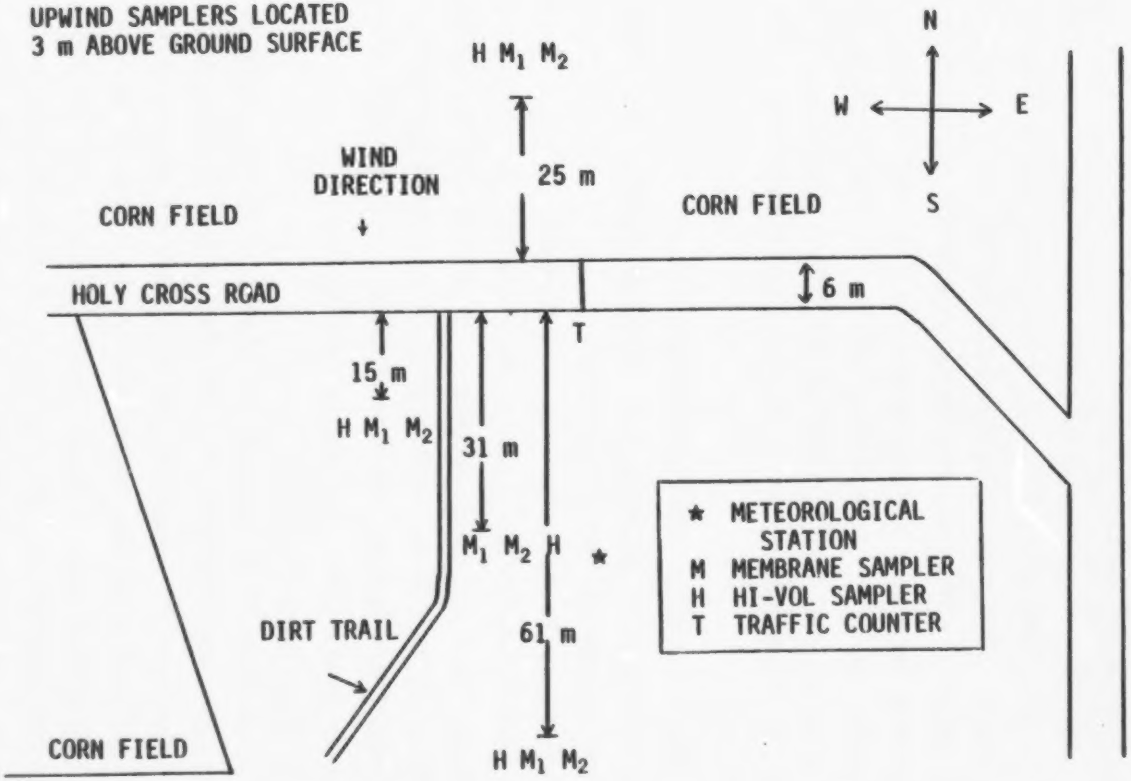

UPWIND SAMPLERS LOCATED
3 m ABOVE GROUND SURFACE
N
W
E
S
WIND DIRECTION
CORN FIELD
CORN FIELD
CORN FIELD
HOLY CROSS ROAD
H M1 M2
25 m
6 m
T
15 m
H M1 M2
31 m
M1 M2 H
61 m
H M1 M2
DIRT TRAIL
★ METEOROLOGICAL STATION
M MEMBRANE SAMPLER
H HI-VOL SAMPLER
T TRAFFIC COUNTER

Figure B-1. Site 1--Holy Cross Road, Harford County, Maryland.

Two membrane samplers and a high-volume air sampler were placed in a row 25 m north of the road. These three samplers measured background (i.e., upwind) particulate concentrations since sampling was conducted when the prevailing wind direction was from the north. These samplers rested on a platform 3 m above ground level with the sampling inlet approximately 3.5 m above ground. (A platform was used because the site was located in a cornfield.) On the south side of the road (i.e., downwind), three rows of samplers were placed parallel to the road at distances of 15 m, 31 m, and 61 m from the road. Each row included a high-volume sampler and either two or three membrane samplers. Downwind samplers were situated at ground level with the sampling inlets 1.5 m above ground level.

Three road surface samples collected on different dates were analyzed for asbestos by electron microscopy. One of the samples was of stone that had been "in place" on the road for several months and was found to contain 0.14 percent chrysotile by weight. Two surface samples were "fresh" stone that was placed on Holy Cross Road during the sampling program on September 26, 1979, and both were found to contain 0.03 percent chrysotile by weight. See Table B-1.

Airborne chrysotile fiber concentrations determined during seven tests at Holy Cross Road are presented in Tables B-2 through B-8. Average (geometric) chrysotile fiber concentrations are plotted versus receptor distance in Figure B-2. (The geometric average rather than the arithmetic average was calculated for split and colocated samples because airborne concentrations of mineral particulates are generally log normally distributed.) Figure B-2 shows that average chrysotile concentrations measured at the furthest downwind distance are higher than the average upwind concentrations for six of the seven tests. During all seven runs, chrysotile fiber concentrations decreased with receptor distance downwind from the road. Run 027, which showed higher upwind concentration, had only one upwind sample analyzed, and thus this value could not be verified. On Runs 032 and 034, the 61-meter downwind sampler experienced mechanical trouble, and the samples had to be voided. For the other five runs, average chrysotile fiber concentrations of the 61 m station, ranged from

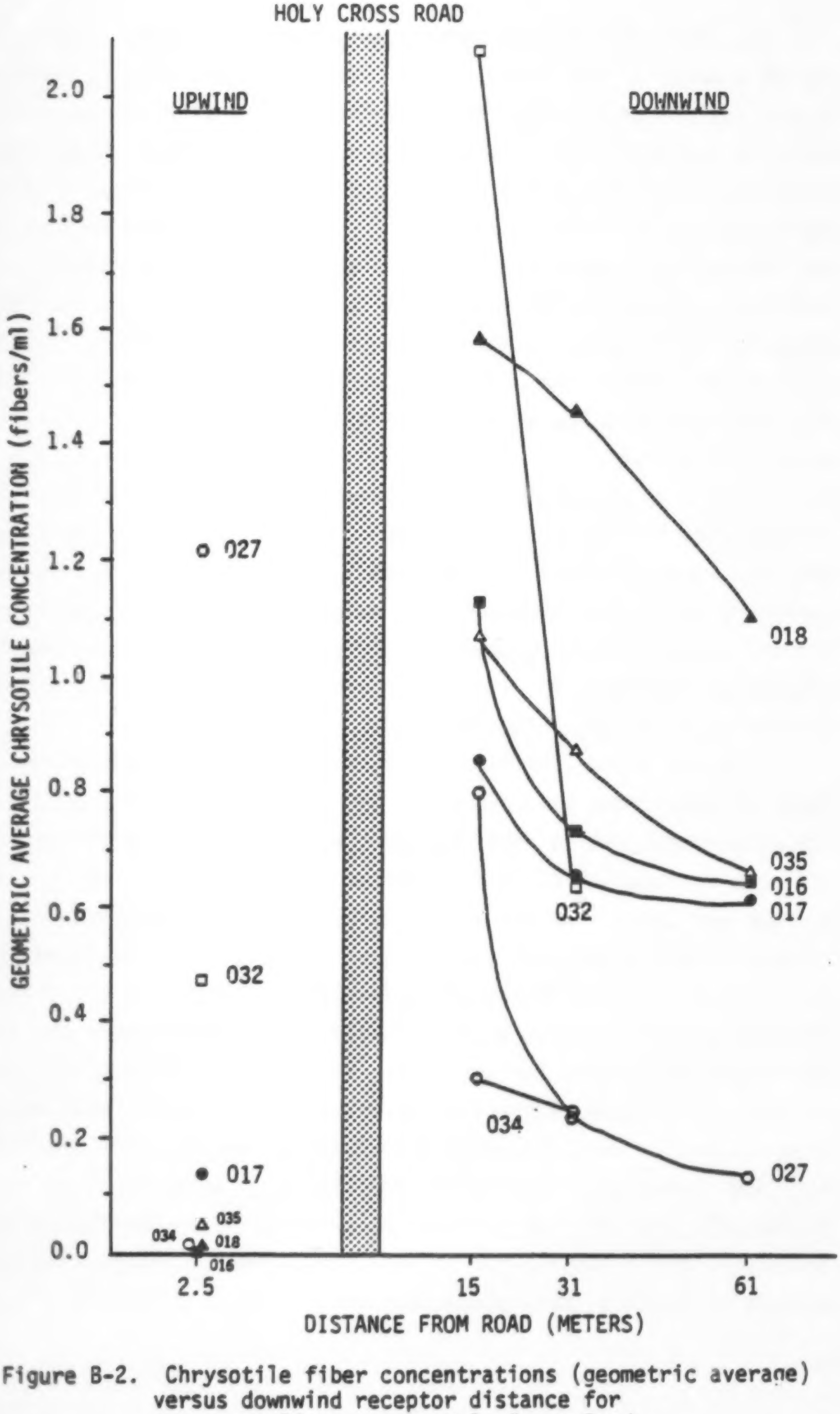


Figure B-2. Chrysotile fiber concentrations (geometric average) versus downwind receptor distance for seven sampling runs at Holy Cross Road.

0.14 to 1.1 fibers/ml, with the typical value being approximately 0.6 fibers/ml.

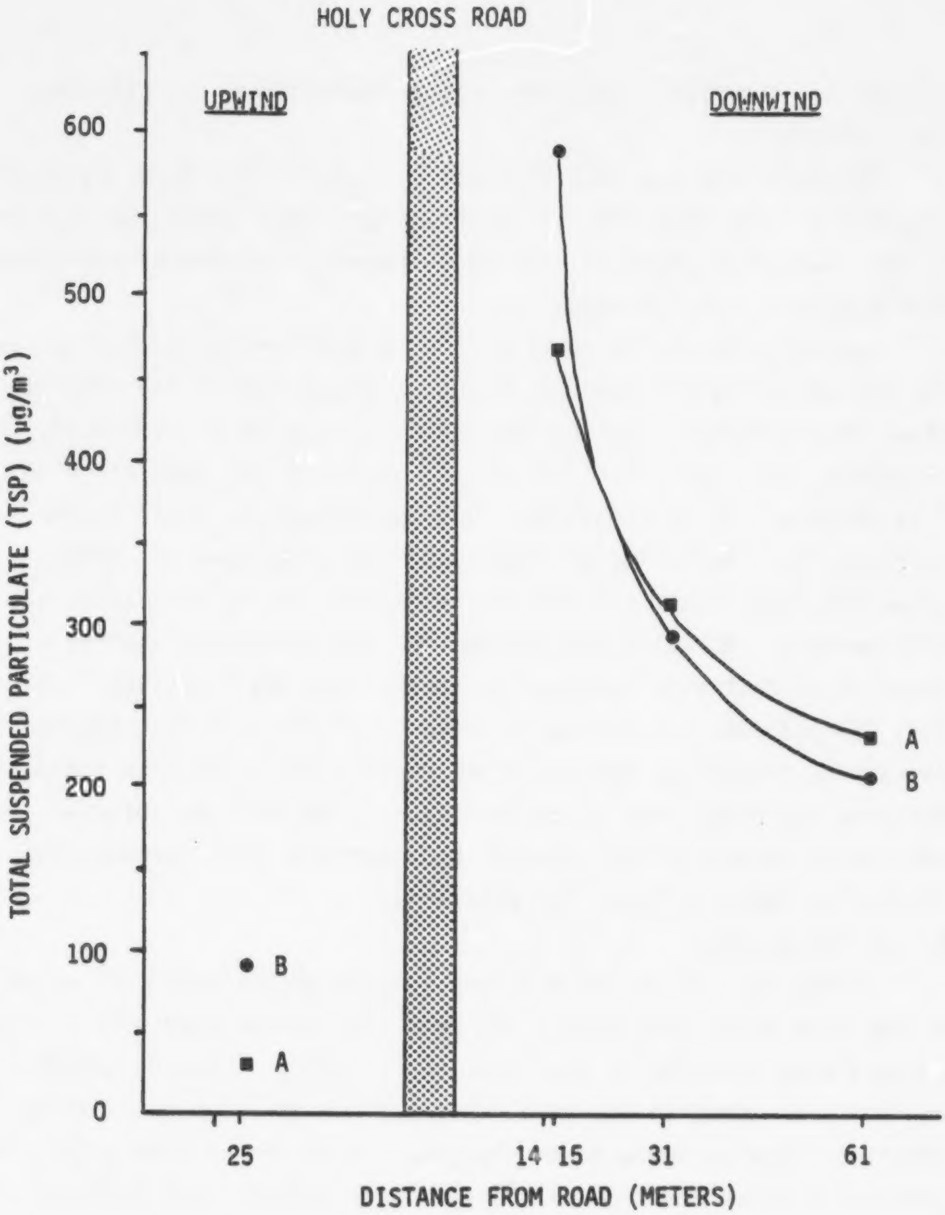
TSP data from two days of testing at Holy Cross Road are shown in Figure B-3. The data similiarly show higher dust concentrations downwind of the road than upwind of the road. Downwind concentrations decreased with distance from the road.

Average airborne chrysotile fiber concentration plotted versus TSP for the two different concentrations of chrysotile in the road stone are shown in Figure B-4. During the series of runs on September 19, 1979 (Runs 016, 017, 018), the chrysotile content of the road stone was 0.14 percent. On September 26, 1979, new stone was added to the road surface. For the series of runs conducted on October 18, 1979, (Runs 032, 034, 035), the chrysotile content of the road stone was 0.03 percent. No value was plotted for the monitoring station 61 m downwind on that date because the station was not functional during Runs 034 and 035. It can be inferred from this plot that crushed roadstone containing increasing amounts of chrysotile will result in increasing airborne concentrations of chrysotile. It can also be inferred that chrysotile emissions for unpaved roads surfaced with serpentinite can be limited by reducing total TSP emissions.

B.4.2 McNabb Road

McNabb Road is an unpaved road located approximately 10 miles east of the Holy Cross Road site. The road is also surfaced with crushed serpentinite produced by the Cedar Hills Quarry. Crushed serpentinite had not been added to the road's surface for at least one year prior to sampling. Upwind/downwind sampling was conducted at this site to assess chrysotile emissions from an older crushed serpentinite surface.

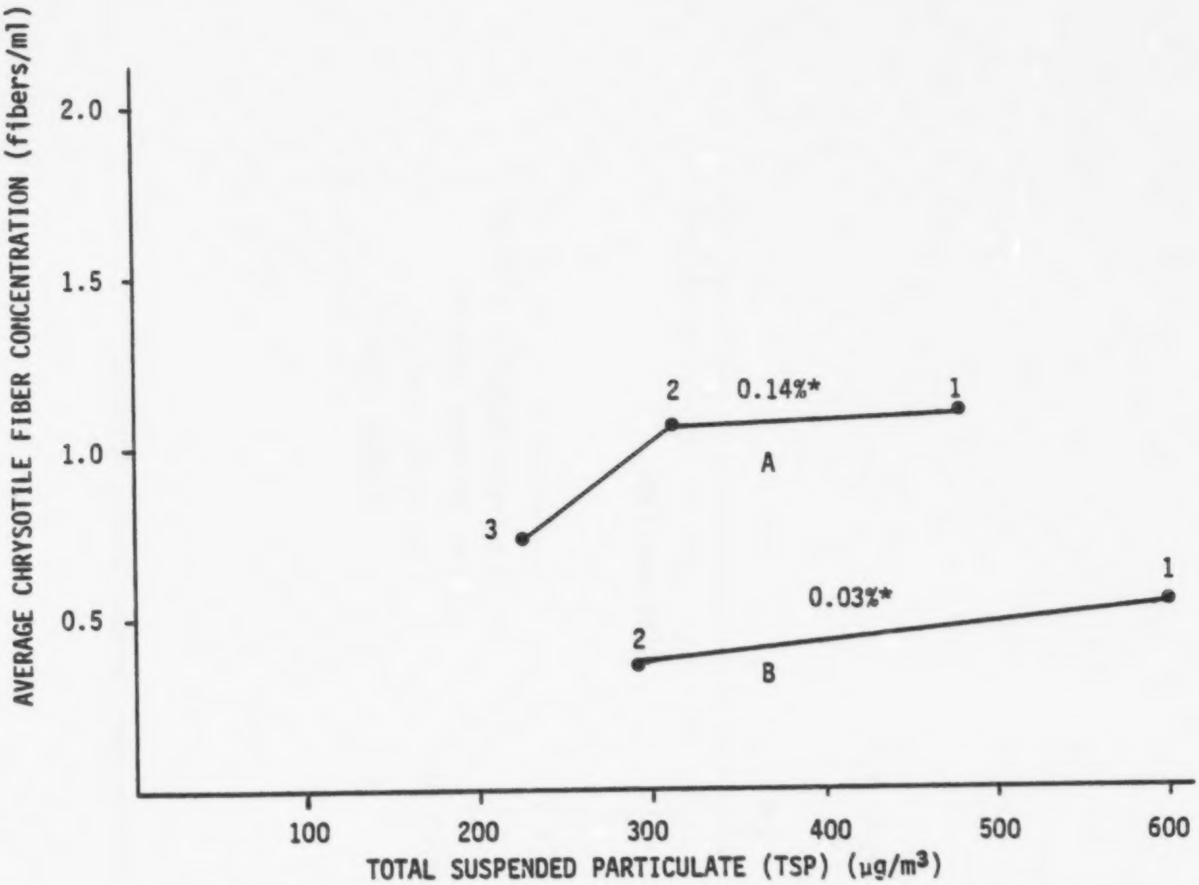
The arrangement of samplers used at McNabb Road is shown in Figure B-5. Three membrane samplers and a high volume air sampler was placed in a row 14 m northeast of the road. These samplers were below road level because of sloping terrain. A similar complement of samplers was placed in a row 25 m southwest of the road at ground level, with the inlets located at 1.5 m above grade. The sampling protocol followed at the McNabb Road site was the same as at other sites. Sampling was conducted when the prevailing wind direction was perpendicular to the road. Wind speed and



A = Runs 016, 017, and 018 were conducted on 9/19/79
(62 vehicle passes during 6 hours of sampling)
(wind speed varied from 6 to 9 m/s)

B = Runs 032, 034, and 035 were conducted on 10/18/79
(80 vehicle passes during 6 hours of sampling)
(wind speed varied from 1 to 4 m/s)

Figure B-3. Total suspended particulate concentrations for two days of sampling at Holy Cross Road.



* = Percent chrysotile by weight in roadstone.
A = Average (geometric) chrysotile concentration for Runs 016, 017, 018 (total of 62 vehicle passes):
  1 = At 15 m downwind (an average of 7 values)
  2 = At 30 m downwind (an average of 14 values)
  3 = At 61 m downwind (an average of 8 values)
B = Average (geometric) chrysotile concentration for Runs 032, 034, 035 (total of 80 vehicle passes):
  1 = At 15 m downwind (an average of 6 values)
  2 = At 31 m downwind (an average of 9 values)

Figure B-4. Average (geometric) chrysotile fiber concentrations versus TSP concentrations for two sets of runs with 2 different chrysotile (by weight) concentrations in the roadstone.

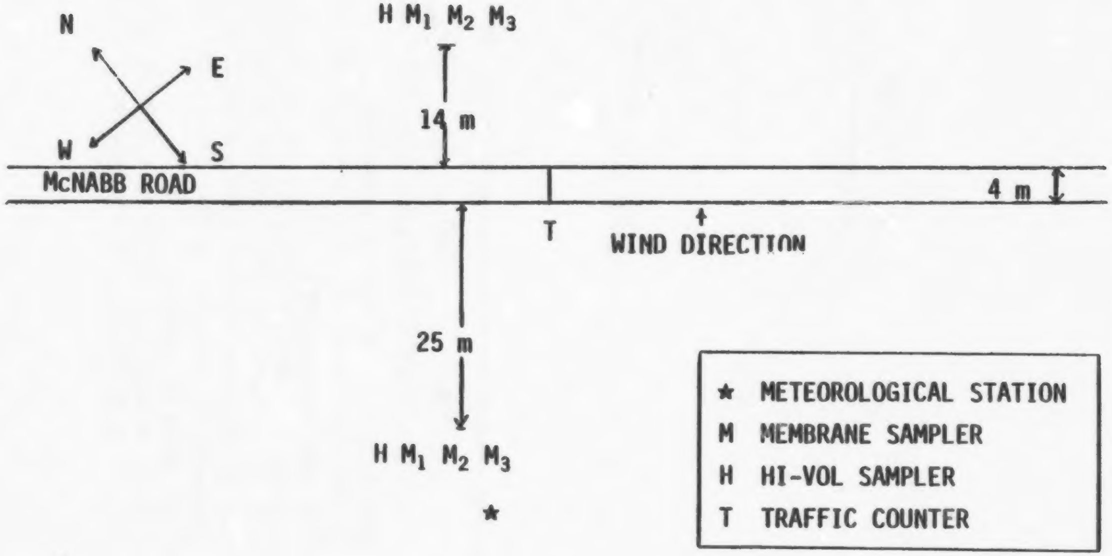

N
E
W
S
H M_1 M_2 M_3
14 m
McNABB ROAD
4 m
T
WIND DIRECTION
25 m
H M_1 M_2 M_3
★
★ METEOROLOGICAL STATION
M MEMBRANE SAMPLER
H HI-VOL SAMPLER
T TRAFFIC COUNTER

Figure B-5. Site 2--McNabb Road, Harford County, Maryland.

direction data represent the average of three hourly readings. The volume of traffic generated along the road during each 2-hour sampling period ranged from 15 to 30 vehicles.

For the seven tests conducted at McNabb Road, downwind chrysotile fiber concentrations ranged from 0.55 to 1.98 fibers/ml while upwind samples had chrysotile fiber concentrations ranging from 0.0 to 1.42 fibers/ml. These results are shown in Tables B-8 through B-15. The upwind and downwind average (geometric) chrysotile fiber concentrations for all seven runs are shown in Figure B-6. The data show that for six of the seven runs, downwind chrysotile fiber concentrations were significantly greater than upwind concentrations. The upwind value for Run 013 (which exceeded the downwind average) represents a single analysis and thus could not be compared with another sample.

McNabb Road had only one upwind sampler location and one downwind sampler location; thus, it is not possible to plot chrysotile concentration versus distance from road. No statistical relationship was found for chrysotile fiber concentration (geometric average) versus number of vehicle passes. The percentage of chrysotile mass in the road surface stone from McNabb Road was determined to be approximately 0.06 percent (Table B-8).

B.4.3 Clear Creek Recreation Area

The Clear Creek Recreation Area consists of 43,000 acres of Bureau of Land Management (BLM) administrated public lands located approximately 115 miles southeast of San Francisco, California. The main access route into the mountainous area is an unpaved canyon road that parallels Clear Creek and passes several campsites.

The area is visited by over 40,000 people annually, 85 percent of whom are operators of off-road vehicles. The dust generated in the area by vehicles and natural forces has raised health concerns because the area is located in a massive outcropping of serpentinite. Air sampling was conducted at a campground to determine ambient chrysotile concentrations in the area. The campsite was located approximately 200 ft from Clear Creek Road, 2 to 3 miles from the entrance to the area. Two personnel samplers, equipped with polycarbonate filters, were placed 300 ft apart. Samplers were placed 1.5 m above ground level. The sampling run lasted

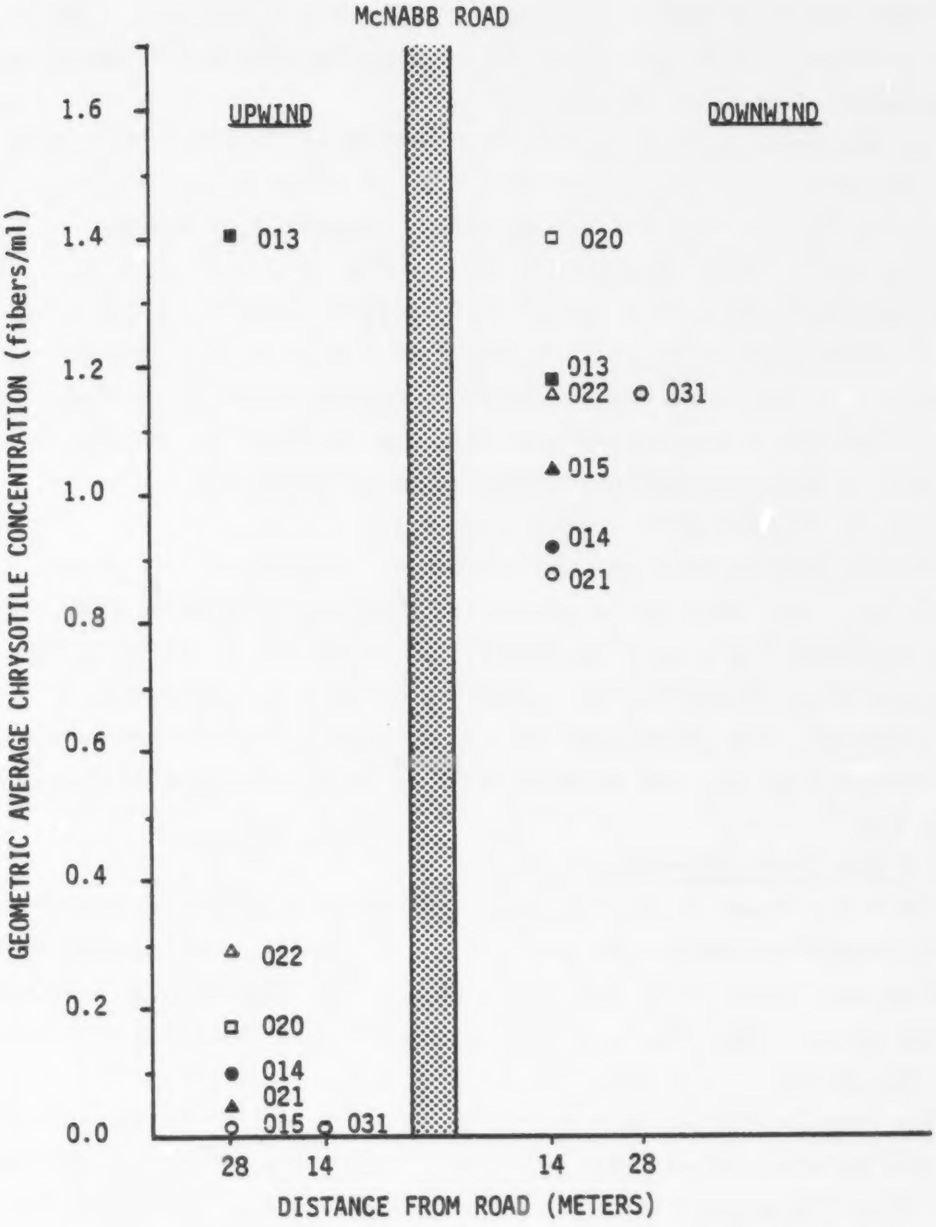


Figure B-6. Upwind and downwind chrysotile fiber concentrations (geometric average) for seven sampling runs at McNabb Road.

approximately 5 hours, during which approximately 25 off-road vehicles were observed in the area. Meteorological conditions were measured hourly during sampling. Winds were moderate and soil conditions were dry. Ambient chrysotile fiber concentrations ranged from 1.26 to 6.39 fibers/ml. These results are shown in Table B-16.

Several airborne particule samples were collected in a vehicle closely following another vehicle traveling along Clear Creek Road. A personnel sampler was also placed at the edge of the road, 1.5 m above grade. Approximately 25 vehicle passes were made by the stationary sampler during each 15-minute sampling run. Chrysotile concentrations determined for the six samples collected in the vehicle ranged from 383 to 972 fibers/ml (geometric average = 549 fibers/ml). Eleven samples collected at the edge of the road ranged from 0.95 to 206 fibers/ml (geometric average = 11.15 f/ml).[2 3] Total volume of air sampled during each run was very small (approximately 0.01 m^3) and thus, the results should be viewed as possible peak exposure levels near the road, not ambient concentration values.

B.4.4 Cedar Hills Quarry

Air sampling was conducted at a site downwind from the Cedar Hills Quarry to determine if quarrying of serpentinite results in significant emissions of chrysotile asbestos to the ambient air. Two membrane samplers and a high-volume air sampler were placed approximately one-quarter mile south of the quarry property boundary. A line of tall trees, a steep creek bank, and a creek were between the samplers and the quarry. Sampling was conducted on three days when the quarry was operating and the prevailing wind direction was north. Each sampling run was conducted for approximately 8 hours. Quarry activity was not monitored during sampling, and the chrysotile content of the stone processed on those days is not known. Atmospheric transport of particulate was partially obscured from the quarry by a line of trees.

Eight airborne particulate samples were found to contain chrysotile fiber concentrations ranging from 0.01 to 0.35 fiber/ml (geometric average = 0.13 fiber/ml). These results are shown on Table B-17.

B.4.5 Woods Creek Quarry

Air sampling was conducted downwind of Woods Creek Quarry to determine if quarrying of serpentinite results in significant emissions of chrysotile asbestos to the ambient air. Six membrane samplers and three high-volume samplers were placed in a row approximately 200 m downwind from the quarry's rock crusher. Each sampling run lasted for approximately 4 hours. Meteorological data were recorded hourly, and quarry activity was noted throughout each samplng run. Emissions from the crushing operation generally were well controlled by wet suppression. Visible emissions occurred at the beginning of a "crushing run" and as a result of vehicular activity around the quarry.

Ten airborne particulate samples collected during 2 days were determined to have chrysotile fiber concentrations ranging from 0.03 to 0.11 fiber/ml (geometric average = 0.05 fiber/ml). These results are shown in Table B-18. Analysis of a single crushed stone sample collected on one of the 2 days from the quarry's rock crusher was determined to contain approximately 0.01 percent chrysotile (by weight).

B.4.6 Duffy Road

Duffy Road is an inclined, unpaved road in Tuolumne County, California, that runs north and south. The road is surfaced with crushed serpentinite produced by the Woods Creek Quarry. Air sampling was conducted at this site to assess airborne asbestos concentrations generated by vehicular traffic. A membrane sampler and a personnel sampler (with sampling inlets about 1.5 m above the ground) were placed 4 m to the east of the road and 10 m to the west of the road. The wind direction during sampling fluctuated from Southwest to South, thus a true background (i.e., upwind) concentration was not obtained. Fifteen to 30 vehicles passed were made during each sampling run. The chrysotile fiber content of three samples collected west of the road (generally upwind) ranged from 0.24 to 3.90 fibers/ml (geometric average = 0.79 fiber/ml). The chrysotile fiber content of the six samples collected east of the road (generally downwind) ranged from 0.17 to 6.33 fibers/ml (geometric average = 1.20 fibers/ml).[2] [3]

B.5 LABORATORY COMPARISONS

Inter- and intralaboratory comparisons were computed for the sums of all possible chrysotile fibers in the airborne particulate samples reported in Tables B-2 through B-18. Samples from the Duffy Road site and Clear Creek Road were not used in calculating these values because of fluctuating wind conditions and because of extremely low air sample volumes. Percent differences were used to compute laboratory comparisons. The coefficient of variation for each case was estimated using the estimated standard deviation of the percent differences divided by the square root of 2. The estimate of the coefficient of variation was then multiplied by 2 to produce the length of the interval (expressed as a percent of the true value) within which two test results should fall 90 percent of the time. The coefficient of variation for inter- and intralaboratory analysis of both split and colocated samples ranged from 34 to 72 percent. The interval length ranged from 68 to 144 percent.[5] These results are shown in Table B-19.

B.6 QUALITY ASSURANCE

All samples analyzed by the participating laboratories were identified with a three-digit code number. Each laboratory conducted inhouse procedures to safeguard against contamination of the samples. In addition, two blank polycarbonate filters were included in the samples analyzed by ORF. The chrysotile fiber concentrations reported for these two samples were 0.02 and 0.07 fibers/ml. One blank polycarbonate filter was included in the samples analyzed by DRI. The chrysotile filter concentration for this sample was reported to be 0.15 fiber/ml.

B.7 CONCLUSIONS

1. Statistical evaluation of the results indicate that ambient chrysotile fiber concentrations can be measured with an acceptable degree of precision. The coefficient of variation for intra- and interlaboratory analysis of split and colocated samples ranged from 34 percent to 72 percent (see Table B-19).

2. Analyses indicate that airborne chrysotile fiber concentrations downwind of unpaved roads surfaced with crushed serpentinite, containing trace amounts of chrysotile and subject to light-to-moderate traffic, are

significantly higher than concentrations upwind of those roads. The geometric mean for 16 upwind samples from the unpaved roads in Harford County, Maryland, was 0.16 fiber/ml. Chrysotile fiber concentrations measured at different distances downwind of the roadways ranged from 0.04 fiber/ml to 2.52 fibers/ml. These downwind concentrations resulted after approximately 30 vehicle passes (at 30 mph) were made across dry, unpaved road surfaces during a 2-hour sampling period.

3. No statistically significant relationship was found for fiber concentrations versus receptor distance downwind, chrysotile content of the roadstone, traffic volume, or wind speed because of variation in the sampling data.

4. Results support the conclusion made earlier by the Montgomery County Department of Environmental Protection that serpentinite quarries are not a major source of airborne asbestos to the surrounding area. Chrysotile concentrations measured near two serpentinite quarries ranged from 0.01 to 0.35 fiber/ml with a geometric average of 0.04 fiber/ml.

5. The chrysotile concentrations reported in this study underestimate the true potential for asbestos exposure from unpaved roads surfaced with serpentinite. TEM analysis revealed that many of the particulate samples contained bundles and sheaves of fibers that have the potential to split into many fibrils. Numerous fibers may eventually be released from a single bundle of fibers. Also, chrysotile fibers that were obscurred by the presence of other material on the filter preparations could not be counted.

6. Fiber concentrations reported in this study are not comparable to fiber concentrations determined by phase-contrast microscopy. Nearly all the fibers detected were short, thin fibers (less than 5 µm in length and less than 0.1 µm in diameter) that would not be counted by phase contrast microscopy because of procedural and analytical limitations.

7. Chrysotile fiber concentrations near campsites in the Clear Creek Recreation Area are approximately 100 times greater than average ambient background concentrations observed at the test sites located in Harford County, Maryland.

TABLE B-1. ANALYSIS OF EIGHT CRUSHED STONE SAMPLES FOR CHRYSOTILE FIBER AND MASS CONTENT PERFORMED BY THE UNIVERSITY OF MINNESOTA AT DULUTH

Sample number	Site and date	Weight of sample analyzed (g)	Total fiber mass (µg/g)	Chrysotile fiber mass (µg/g)	% Chrysotile of total fiber mass	% Chrysotile sample analyzed
[R-1]	Clear Creek Road 11/16/79	2.19 E-7	3.39 E 5	3.25 E 5	95.5	33.0
[R-4]	Wood Creek Quarry 12/12/79	8.50 E-5	1.30 E 2	9.41 E 1	72.4	0.01
[R-5]	Duffy Road 12/08/79	2.455 E-6	1.24 E 4	6.56 E 3	52.9	0.66
[R-7]	McNabb Road 09/05/79	8.67 E-5	2.33 E 3	5.74 E 2	24.6	0.06
[R-8]	Holy Cross Road 10/18/79	3.955 E-5	1.95 E 3	3.34 E 2	17.1	0.03
[R-9]	Holy Cross Road 09/26/79	9.62 E-5	2.93 E 3	2.57 E 2	8.8	0.03
[R-10]	Clear Creek camping area 12/18/79	9.12 E-6	1.49 E 3	7.40 E 2	49.7	0.07
[R-11]	Holy Cross Road 09/05/79	8.96 E-6	1.88 E 3	1.38 E 3	73.4	0.14

TABLE B-2. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM HOLY CROSS ROAD

Site:	Holy Cross Road
Run:	016
Date and time:	09/19/79 10:15-12:15
Vehicle passes:	30
Wind speed:	6-8 m/s
Road silt:	3.9 percent
Chrysotile content of road stone:	0.14 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
25 m upwind	m_1	10.85	228	ORF	0.00
15 m downwind	m_1	10.86	229	DRI	1.17
	m_2	10.85	230	DRI	1.09
					1.13 (avg.)[b]
31 m downwind	m_1	10.66	231	DRI	0.80
			324	DRI	1.59
			325	ORF	0.68
	m_2	10.84	273	DRI	1.32
	m_3	10.84	232	ORF	0.80
					0.74 (avg.)[b]
61 m downwind	m_1	10.80	274	ORF	0.45
	m_2	10.80	275	DRI	0.92
					0.64 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[b] Geometric average.

TABLE B-3. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM HOLY CROSS ROAD

Site: Holy Cross Road
Run: 017
Date and time: 09/19/79 13:30 to 15:30
Vehicle passes: 12
Wind speed: 7-9 m/s
Road silt: 2.5 percent
Chrysotile content of road stone: 0.14 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
25 m upwind	m_1	10.80	321	DRI	0.36
			233	DRI	0.98
			320	ORF	0.02
	m_2	10.80	234	DRI	0.04
					0.13 (avg.)[b]
15 m downwind	m_1	10.85	235	DRI	1.09
			236	ORF	1.23
	m_2	10.84	237	ORF	0.47
					0.86 (avg.)[b]
31 m downwind	m_1	10.84	238	DRI	0.75
	m_2	10.85	276	ORF	0.49
	m_3	10.84	239	DRI	0.75
					0.65 (avg.)[b]
61 m downwind	m_1	10.71	277	DRI	0.88
	m_2	10.71	278	DRI	0.76
			327	DRI	0.91
			328	ORF	0.24
					0.62 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[b] Geometric average.

TABLE B-4. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSION FROM HOLY CROSS ROAD

Site:	Holy Cross Road
Run:	018
Date and time:	09/19/79 16:25 to 18:25
Vehicle passes:	20
Wind speed:	6-9 m/s
Road silt:	3.3 percent
Chrysotile content of road stone:	0.14 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
25 m upwind	m_1	10.85	240	ORF	0.02
	m_2	10.85	241	DRI	0.03
					0.02 (avg.)[b]
15 m downwind	m_1	10.80	242	ORF	1.87
	m_2	10.80	243	DRI	1.34
					1.58 (avg.)[b]
31 m downwind	m_1	10.84	244	ORF	1.09
	m_2	10.84	279	DRI	2.10
			281	DRI	2.52
	m_3	10.84	245	DRI	1.98
			246	ORF	0.73
			326	ORF	1.15
					1.46 (avg.)[b]
61 m downwind	m_1	10.76	280	DRI	1.33
	m_2	10.75	282	ORF	0.92
					1.11 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Reserach Institute.

[b] Geometric average.

NOTE: Total suspended particulate concentrations determined for the 6 hours of sampling (runs 016, 017, and 018) on 9/19/79 were as follows: 25 m upwind--30 μg/m^3; 15 m downwind--471 μg/m^3; 31 m downwind--312 μg/m^3; 61 m downwind--230 μg/m^3.

TABLE B-5. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM HOLY CROSS ROAD

Site:	Holy Cross Road
Run:	027
Date and time:	09/26/79 12:55 to 14:55
Vehicle passes:	20
Wind speed:	3-5 m/s
Road silt:	3.0 percent
Chrysotile content of road stone:	0.03 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
25 m upwind	m_2	10.85	247	DRI	1.22
15 m downwind	m_2	10.80	249	DRI	1.37
			319	ORF	0.26
			318	DRI	1.42
					0.80 (avg.)[b]
31 m downwind	m_1	10.84	250	ORF	0.13
	m_3	10.75	251	DRI	0.73
			252	ORF	0.14
					0.24 (avg.)[b]
61 m downwind	m_1	10.80	316	ORF	0.04
	m_2	10.80	317	DRI	0.52
					0.14 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[b] Geometric average.

TABLE B-6. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM HOLY CROSS ROAD

Site:	Holy Cross Road
Run:	032
Date and time:	10/18/79 10:42 to 12:42
Vehicle passes:	20
Wind speed:	2-4 m/s
Road silt:	3.6 percent
Chrysotile content of road stone:	0.03 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
25 m upwind	m_1	10.76	200	DRI	0.68
			206	DRI	0.33
					0.47 (avg.)[b]
15 m downwind	m_2	10.35	202	DRI	2.09
31 m downwind	m_1	10.71	203	DRI	1.60
			207	DRI	0.44
	m_2	10.68	204	ORF	0.05
	m_3	10.71	205	DRI	0.48
					0.64 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[b] Geometric average.

TABLE B-7. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM HOLY CROSS ROAD

Site:	Holy Cross Road
Run:	034
Date and time:	10/18/79 13:25 to 15:25
Vehicle passes:	30
Wind speed:	1-4 m/s
Road silt:	3.6 percent
Chrysotile content of road stone:	0.03 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
25 m upwind	m_1	10.75	209	ORF	0.01
15 m downwind	m_1	10.84	210	ORF	0.26
	m_2	10.84	211	ORF	0.28
			323	ORF	0.29
			322	DRI	0.45
					0.31 (avg.)[b]
31 m downwind	m_1	10.66	214	ORF	0.16
	m_2	10.91	213	ORF	0.08
			212	DRI	1.10
					0.25 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[b] Geometric average.

TABLE B-8. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM HOLY CROSS ROAD

Site: Holy Cross Road
Run: 035
Date and time: 10/18/79 16:08 to 18:08
Vehicle passes: 30
Wind speed: 2-3 m/s
Road silt: 3.6 percent
Chrysotile content of road stone: 0.03 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
25 m upwind	m_2	10.80	216	ORF	0.05
			217	ORF	0.03
					0.04 (avg.)[b]
15 m downwind	m_1	10.85	218	DRI	1.07
31 m downwind	m_1	10.76	221	DRI	0.99
	m_2	10.71	222	ORF	0.76
					0.87 (avg.)[b]
61 m downwind	m_1	10.94	224	DRI	0.41
			225	DRI	1.03
					0.65 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[b] Geometric average.

NOTE: Total suspended particulate concentrations determined for the 6 hours of sampling (Runs 032, 034, and 035) on 10/18/79 were as follows: 25 m upwind--91 $\mu g/m^3$; 15 m downwind--593 $\mu g/m^3$; 31 m donwind--292 $\mu g/m^3$; 61 m donwind--205 $\mu g/m^3$.

TABLE B-9. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM McNABB ROAD

Site:	McNabb Road
Run:	013
Date and time:	09/18 10:00 to 12:00
Vehicle passes:	20
Wind speed:	3-10 m/s
Road silt:	4.8 percent
Chrysotile content of road stone:	0.06 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
28 m upwind	m_1	10.84	265	DRI	1.41
14 m downwind	m_1	10.86	266	ORF	0.96
	m_3	10.80	264	DRI	1.50
					1.18 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute

[b] Geometric average.

TABLE B-10. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM McNABB ROAD

Site: McNabb Road
Run: 014
Date and time: 09/18/79 12:45 to 14:45
Vehicle passes: 15
Wind speed: 7-9 m/s
Road silt: 3.7 percent
Chrysotile content of road stone: 0.06 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
28 m upwind	m_2	10.80	331	ORF	0.00
			263	DRI	1.05
					0.10 (avg.)[b]
14 m downwind	m_1	10.84	267	DRI	1.49
	m_2	10.84	268	DRI	1.98
			269	ORF	0.69
			329	ORF	0.60
	m_3	10.85	270	ORF	0.55
					0.92 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.
[b] Geometric average.

TABLE B-11. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM McNABB ROAD

Site:	McNabb Road
Run:	015
Date and time:	09/18/79 15:25 to 17:25
Vehicle passes	30
Wind speed:	7-10 m/s
Road silt:	4.1 percent
Chrysotile content of road stone:	0.06 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
28 m upwind	m_3	10.80	260	DRI	0.05
14 m downwind	m_2	10.84	262	ORF	0.88
	m_3	10.84	272	DRI	1.22
					1.04 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute

NOTE: Total suspended particulate concentrations determined for the 6 hours of sampling (Runs 013, 014, and 015) on 9/18/79 were as follows: 28 m upwind--26 μg/m^3; 14 m downwind--528 μg/m^3.

TABLE B-12. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM McNABB ROAD

Site:	McNabb Road
Run:	020
Date and time:	09/20/79 10:50 to 12:50
Vehicle passes:	29
Wind speed:	2-4 m/s
Road silt:	3.2 percent
Chrysotile content of road stone:	0.06 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
28 m upwind	m_2	10.80	284	DRI	0.17
14 m downwind	m_2	10.85	285	DRI	1.54
			290	DRI	1.30
					1.41 (avg.)[b]

[a] DRI = Denver Research Institute.

[b] Geometric average.

TABLE B-13. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM McNABB ROAD

Site: McNabb Road
Run: 021
Date and time: 09/20/79 13:20 to 15:20
Vehicle passes: 30
Wind speed: 2-5 m/s
Road silt: 4.9 percent
Chrysotile content of road stone: 0.06 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
28 m upwind	m_1	10.85	291	ORF	0.01
14 m downwind	m_1	10.86	286	ORF	0.70
			289	ORF	1.03
	m_2	10.80	288	ORF	0.77
		10.82	287	DRI	1.10
					0.88 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Foundation.

[b] Geometric average.

TABLE B-14. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM McNABB ROAD

Site:	McNabb Road
Run:	022
Date and time:	09/20/79 15:55 to 17:55
Vehicle passes:	30
Wind speed:	3-5 m/s
Road silt:	3.5 percent
Chrysotile content of road stone:	0.06 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
28 m upwind	m_3	10.85	294	DRI	0.29
14 m downwind	m_3	10.80	293	ORF	1.16
	m_2	10.80	292	DRI	1.16

[a] ORF = Ontario Research Foundation.
DRI = Denver Reserach Institute.

NOTE: Total suspended particulate concentrations determined for the 6 hours of sampling (runs 020, 021 and 022) on 9/20/80 were as follows: 28 m upwind--36 μg/m³; 14 m downwind--509 μg/m³.

TABLE B-15. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS FROM McNABB ROAD

Site: McNabb Road
Run: 031
Date and time: 09/27/79 14:00 to 16:00
Vehicle passes: 25
Wind speed: 1-4 m/s
Road silt: 3.7 percent
Chrysotile content of road stone: 0.06 percent

Location	Sampler	Volume sampled (m^3)	Filter	Laboratory[a]	Chrysotile concentration (fibers/ml)
14 m upwind	m_2	10.84	303	ORF	0.00
28 m downwind	m_2	10.80	299	DRI	1.78
	m_2	10.80	300	ORF	1.04
	m_3	10.80	298	ORF	0.84
					1.16 (avg.)[b]

[a] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[b] Geometric average.

TABLE B-16. SAMPLING AND ANALYSIS OF AMBIENT CHRYSOTILE ASBESTOS CONCENTRATIONS IN THE CLEAR CREEK FEDERAL RECREATIONAL AREA, SAN BENITO COUNTY, CALIFORNIA

Location	Date (1979)	Filter	Sampling duration (minutes)	Total volume sampled[a] (m^3)	Chrysotile concentration[b] (fibers/ml)
Camping area	12/15	73	263	0.419	3.05
		145[c]	263	0.419	1.26
		74	267	0.566	6.39
					2.90 (avg.)[d]

[a] All samples collected using personnel air samplers with air flow rates of approximately 2 ℓ/min.

[b] Analyses performed by Denver Research Institute.

[c] Split sample of Filter 73.

[d] Geometric average.

(Note: On the day of sampling, approximately 40 visitors were observed in the area. The wind was from the SW, 1-3 m/s. Soil surface conditions were very dry.)

TABLE B-17. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS NEAR A SERPENTINITE QUARRY IN THE EASTERN UNITED STATES

Date (1979)	Run	Wind direction and speed	Sampler[a]	Volume sampled (m^3)	Filter	Laboratory[b]	Chrysotile concentration (fibers/ml)
09/26	029	N, 3-5 m/s	m_1	43.30	295	DRI	0.35
			m_2	42.44	314	ORF	0.09
10/17	033	SW, 0-3 m/s	m_1	44.25	305	ORF	0.01
			m_2	45.15	304	DRI	0.04
10/18	036	N, 0-4 m/s	m_1	44.88	306	ORF	0.01
	036		m_2	44.52	307	ORF	0.01
					309	ORF	0.01
					308	DRI	0.13
							0.03 (avg.)[c]

[a] All samples were collected approximately 400 m south of Cedar Hill Quarry.

[b] ORF = Ontario Research Foundation.
DRI = Denver Research Institute

[c] Geometric average.

TABLE B-18. SAMPLING AND ANALYSIS OF CHRYSOTILE ASBESTOS EMISSIONS NEARS A SERPENTINITE QUARRY IN THE WESTERN UNITED STATES

Date (1979)	Run	Sampler[a]	Volume sampled (m^3)	Filter	Laboratory[b]	Chrysotile concentration (fibers/ml)
12/12	C-08	m_4	20.27	58	ORF	0.04
				134	ORF	0.10
12/12	C-08	m_2	20.27	142	ORF	0.04
12/13	C-09	m_1	28.48	68	ORF	0.03
				143	DRI	0.05
12/13	C-09	m_2	28.86	66	DRI	0.11
12/13	C-09	m_3	18.43	70	DRI	0.06
				135	DRI	0.06
12/13	C-09	$_4$	26.86	71	ORF	0.06
				144	ORF	0.03
						0.05 (avg.)[c]

[a] All samples collected approximately 200 m downwind of Woods Creek Quarry, Tuolumne County, California. On both sampling days wind was from the north at 2-4 m/s.

[b] ORF = Ontario Research Foundation.
DRI = Denver Research Institute.

[c] Geometric average of the ten samples.

TABLE B-19. STATISTICAL EVALUATION OF CHRYSOTILE FIBER CONCENTRATIONS REPORTED BY TWO LABORATORIES ANALYZING SPLIT AND COLOCATED SAMPLES[5]

Type of sample	Comparison	Coefficient of variation (%)	Interval length (%)[a]
Split samples	Within ORF[b]	40	80
	Within DRI[c]	44	88
	Between labs	67	134
Colocated samples	Within ORF	34	68
	Within DRI	50	100
	Between labs	72	144

[a] Interval length = Percent of the true value within which two test results should fall 90 percent of the time.

[b] ORF = Ontario Research Foundation.

[c] DRI = Denver Research Institute

B.8 REFERENCES

1. Electron Microscope Measurement of Airborne Asbestos Concentrations--A Provisional Methodology Manual. U.S. Environmental Protection Agency. Research Triangle Park, N.C. Publication No. EPA-600/2-77-178. Revised June 1978. 48 p.

2. Fitzpatrick J. Analysis of Airborne Particulate Samples for Asbestos. Denver Research Institute. Denver, Colo. July 7, 1981.

3. Dillon, M. J., and P. Richardson. Asbestos Analyses for Ambient Monitoring Study of Production and Use of Crushed Stone. Ontario Research Institute. Mississauga, Ontario. June 25, 1981. 88 p.

4. Marklund, D., et al. Analysis of Crushed Rock Sample Specimens for Measurement of Asbestos Content by Electron Microscopy. Environmental Services Laboratory, University of Minnesota, Duluth. Duluth, Minn. May 14, 1981. 11 p.

5. Memo from Fitz-Simons, T., EPA/ARB, to Drago, R., EPA:EMSL. May 4, 1981. Statistical evaluation of asbestos sampling results. 11 p.